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COST COMPARISON OF THE NAVY'S AIR COMBAT ENVIRONMENT TEST AND EVALUATION FACILITY (ACETEF) AND THE AIR FORCE'S ELECTRONIC COMBAT INTEGRATED TEST (ECIT)

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Congress directed DoD to review the costs and capabilities associated with the use of the Navy's Air Combat Environment Test and Evaluation Facility (ACETEF) to satisfy aircraft electronic combat ground testing requirements in lieu of the Air Force developing its own Electronic Combat Integrated Test (ECIT) capability. This paper examines various ACETEF and ECIT capability options that could reasonably satisfy stated Air Force and Navy needs in terms of costs, effectiveness, and other qualitative considerations. Costs include investments for facilities, equipment, and software; deployment costs for testing at other than the primary flight test location; and operating costs for running the facilities over a 20-year period. Effectiveness is defined as the percentage of requirements satisfied by the various facility and capability alternatives. Based on the analysis, the Air Force ECIT proposal is the preferred alternative for meeting both stated testing and many variations in those needs.

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Contract MDA 903 89 C 0003
Task T-N7-559

PREFACE

This paper was prepared by the Institute of Defense Analyses (IDA) for the Office of the Director, Test and Evaluation, under contract MDA 903 89 C 0003, Task Order T-N7-559, issued 16 November 1987/30 August 1991, and amendments. The objective of this portion of the task was to identify the most cost-effective alternative among Navy and Air Force capability options that satisfy electronic combat ground testing requirements.

This work was reviewed within IDA by Robert Dighton, Thomas Frazier, Stanley Horowitz, and Alfred Victor.

EXECUTIVE SUMMARY

SUMMARY OF RESULTS

The Navy and Air Force estimate their requirements for electronic combat/avionics testing at installed systems test facilities (ISTFs) to be about 7 shifts per day beginning in the mid-1990s. These requirements can only be satisfied by expanding current ISTF capacity. Such expansion must include a large anechoic chamber (LAC) because about half of the 7-shift estimate is dedicated to testing of large aircraft.

Proposed expansions to the existing Air Combat Environmental Test and Evaluation Facility (ACETEF) would satisfy only 36% of Service requirements and none of the large chamber requirements. Consequently, we considered three additional alternatives:

- Build a large chamber at ACETEF
- Develop an Electronic Combat Integrated Test (ECIT) capability to integrate with the existing large chamber (Benefield Anechoic Facility or BAF) at Edwards Air Force Base
- Pursue both of the above simultaneously.

Pursuing both simultaneously is the most expensive option and satisfies about 94% of the stated requirements. Another strategy would be to select one of the other two less costly options and defer further ISTF expansion until additional testing experience has been gained.

The two less costly alternatives, building an LAC at ACETEF or developing the ECIT capability at Edwards, would cost about the same; however, developing an ECIT capability would satisfy more of both the requirements and the qualitative considerations. Therefore, our recommendation is to develop the ECIT capability now and retain the option to add an LAC at ACETEF if future demands warrant. To ensure the ECIT cost benefits are realized, the Air Force should commit funding to complete a full ISTF in time to test F-22 electronic combat systems at that facility.

The subsections that follow give the background on this issue and explain how we arrived at the above-stated results.

BACKGROUND

Modern aircraft electronic combat/avionics systems are becoming increasingly complex and testing of such systems is becoming more difficult. To address this difficulty, the Department of Defense (DoD) has placed considerable emphasis on a class of integrated ground test complexes known as installed systems test facilities (ISTFs). The Navy operates such a facility, the Air Combat Environmental Test and Evaluation Facility (ACETEF), at Patuxent River Naval Air Station (NAS), Maryland.

The DoD FY 1992 budget request to Congress included $10 million for the Air Force (AF) to begin development of the Electronic Combat Integrated Test (ECIT) facility at the AF Flight Test Center, Edwards Air Force Base (AFB), California. The Senate Appropriations Committee deferred action on the request, eliminated all 1992 funding, and noted that the total ECIT upgrade would cost $250 million. Also, the Committee stated that ECIT was not justified because of "the possibility of substituting a less costly modification to a Navy facility and because firm test requirements for ECIT are lacking" [1]. The Committee directed DoD to compare the cost of modifying the Navy's ACETEF with the cost of upgrading ECIT. The results were to be submitted with the FY 1993 budget request.

Subsequently, the House and Senate Appropriations Conference Committee's report of 18 November 1991 also eliminated the $10 million funding request and directed that no other funds be used to support the ECIT upgrade. The Conference Committee asked that DoD "review the capabilities of the Navy's Air Combat Environment Test and Evaluation Facility to determine the feasibility of using this facility for Air Force testing requirements" and provide the results to the House and Senate Appropriations Committees.

In response to the congressional request, the Director, Test and Evaluation, Under Secretary of Defense (Acquisition), asked the Institute for Defense Analyses (IDA) to assess the costs associated with ACETEF and ECIT alternatives and the capabilities they represent with respect to Air Force and Navy requirements. IDA was further asked to make use of Service estimates to the maximum extent possible. The results of our subsequent analysis depended on three parameters: the requirements for electronic combat/avionics installed systems test facilities, the costs of various combinations of ISTFs at Patuxent River NAS and Edwards AFB, and the resulting capabilities to meet the Service requirements.

OVERVIEW OF ANALYSIS

Test Requirements

First, we reviewed future Navy and Air Force aircraft program requirements for installed systems test facilities. Table ES-1 summarizes those requirements. The combined Navy and Air Force test requirements are equivalent to almost 7 shifts of anechoic chamber use per day. About half of the requirements are for aircraft that require a large anechoic chamber (LAC).

Table ES-1. Future Requirements for ISTF Chambers (Average Shifts Per Day)

User	Small Anechoic Chamber	Large[a] Anechoic Chamber	Total
Navy	2.0	1.8	3.8
Air Force	1.4	1.7	3.1
Total	3.4	3.5	6.9

[a] "Large" requirements are those that cannot be satisfied in the existing ACETEF chamber.

We judged these requirements to be reasonable because:

(1) They were validated by program managers (PMs), who are not motivated to overstate test requirements.

(2) They were consistent with the trends of increasing proportions of flyaway costs attributable to electronic combat/avionics systems. Such systems incorporate complex technology and represent developmental and operational challenges.

(3) They were consistent with Navy experience at ACETEF. The Navy uses the ACETEF chamber an average of 1.5 shifts per day, 5 days per week, for small aircraft now, and expects usage to increase to an average of 2 shifts per day by 1994 and beyond. The Navy estimates its requirements for large chamber testing, for which there is no current capability, at 1.8 shifts per day. This estimate is consistent with the Navy's small chamber experience. Air Force requirements are comparable to those of the Navy, both in total and by individual aircraft, and like the Navy's requirements, may increase as experience is gained with the use of ACETEF-type facilities.

(4) Ground testing is cost-effective. While not a complete substitute for flight testing, ground testing can accomplish many test objectives at about 12% of the cost of performing similar objectives in flight testing. Moreover, ground testing can synthesize high-density electronic signal environments, which cannot be created for flight testing.

To further test their reasonableness, we conducted sensitivity analyses at 50%, 75%, 125%, and 150% of the stated requirements.

Alternatives To Satisfy Requirements

We considered four alternatives that satisfy varying levels of the total test requirements. Each alternative includes the cost and capabilities of currently programmed enhancements to ACETEF contained in the Central Test and Evaluation Investment Program (CTEIP). In order of increasing cost and ability to meet requirements the alternatives are as follows:

- Alternative 1: Operate ACETEF at 2.5 shifts per day instead of the current 1.5. Optimal scheduling would raise the percentage of the requirements that could be met from 22% to 36%. This alternative would not provide for a large anechoic chamber, and almost half of the services' requirements are for testing in a large anechoic chamber.
- Alternative 2: Build a large anechoic chamber at Patuxent River NAS and connect it to the ACETEF laboratories. With optimal scheduling, ACETEF could support 2 shifts in each chamber for a total of 4. This alternative would raise the percentage of requirements met from 22% to 57%.
- Alternative 3: Develop the ECIT to serve the large chamber at Edwards AFB (Benefield Anechoic Facility or BAF) and operate ACETEF at 2.5 shifts per day. ECIT would also operate at 2.5 shifts per day. This alternative would accommodate 72% of the stated requirements instead of the current 22%.
- Alternative 4: Build the LAC at ACETEF and develop the ECIT at Edwards, combining Alternatives 2 and 3. This alternative would accommodate 94% of the stated Navy and AF requirements.

Figure ES-1 shows graphically the amount of total test requirements each of the alternatives could satisfy as compared to the baseline.

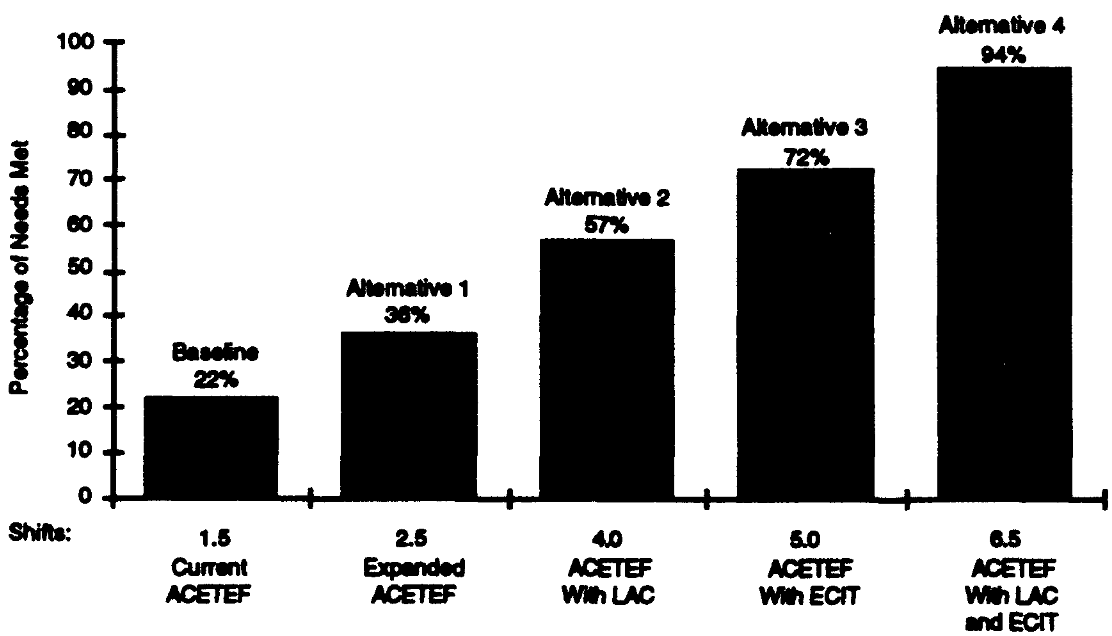

Figure ES-1. Requirements Satisfied by the Alternatives

Costs and Effectiveness of Alternatives

In estimating the costs associated with the four alternatives, we considered only those costs that differed among the alternatives. Costs such as those incurred by actual testing were not included when they were assumed to be the same at one location as another. Major cost elements considered were investment, 20 years of operations, and deployment. Only the last category's cost estimate had significant uncertainty. The F-22 Systems Program Office (SPO) estimated that it would cost $309 million more in constant FY 1992 dollars to deploy to ACETEF that portion of the F-22's EC/avionics ground test program involving an ISTF than to conduct that ground testing at Edwards, where flight testing and other ground testing will be conducted. This estimate included the cost to construct a systems integration laboratory (SIL) with two avionics bench-test lines at Patuxent River NAS adjacent to ACETEF and its chamber.

The AF rationale for this estimate was that the F-22 is a major new development that incorporates the most technologically advanced (integrated) electronic combat/avionics systems ever undertaken by the DoD. As a result, the Air Force considered it essential that a SIL (or hardware-in-the-loop) facility be collocated with the ISTF if the ISTF is not collocated with the flight test program. The $309 million represents the total cost to the F-22 program associated with build-up and 26 months with an F-22 avionics test aircraft in an anechoic chamber at ACETEF. At the other end of the spectrum, similar deployment to ACETEF of previous operational aircraft for tests of limited duration and scope without a collocated SIL was estimated to cost only $15 million.

IDA developed a "middle ground" deployment estimate of $140 million, which included building a single-line SIL at ACETEF with fewer people, fewer spares, less equipment, and less duplicative flight testing than included in the F-22 estimate. We believed this estimate to be a reasonable balance between risk and affordability.

Table ES-2 shows the investment, 20 years of operation, and deployment cost of the four alternatives using the IDA deployment estimate. (All three deployment estimates, $15 million, $140 million, and $309 million, are covered in Section VI of the main report and in the requirements excursions in Appendix E.) The details of these cost estimates are presented in Section VI and in the appendices.

Figure ES-2 illustrates the discounted costs for the same four alternatives shown in Table ES-2. It also shows the difference between the percent of test requirements (needs) met by each alternative and the 22% met by the current ACETEF operation. The scale at

the left of the figure measures the costs of each alternative, and the scale at the right measures the percentage of needs met. Note that the F-22 deployment costs from Edwards AFB to Patuxent in Alternatives 1 and 2 offset much of the increased investment and operations costs for Alternatives 3 and 4 that include developing the ECIT facility at Edwards.

Table ES-2. Costs of Alternatives

	Description of Alternative	Millions of Constant FY 1992 Dollars	Millions of Discounted FY 1992 Dollars
1	Provide 2.5 Shifts at ACETEF	$262	$167
2	Build LAC at Patuxent with 4-Shift Capacity	$454	$249
3	Develop ECIT at Edwards (and Alt. 1 ACETEF)	$486	$264
4	Build LAC and ECIT (Alt. 2 + Alt. 3)	$589	$328

Note: Costs include future investments, 20 years of operations, and deployments, using IDA's estimate for F-22 deployment. Discounted costs are at 10% per annum.

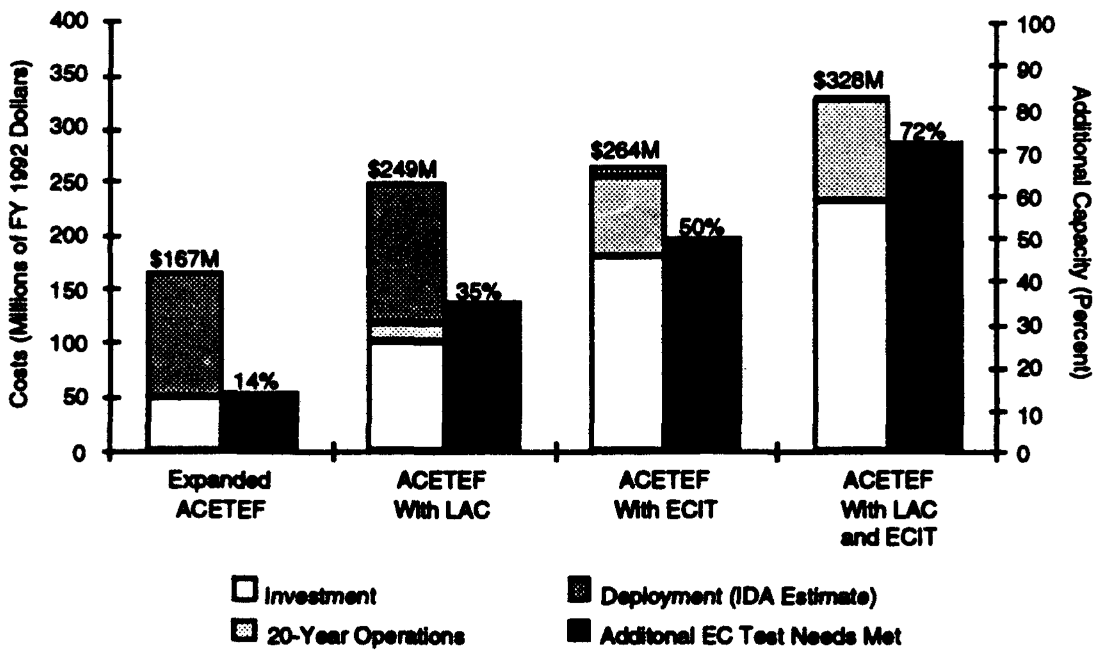

Figure ES-2. Comparison of Alternatives

Findings

The three general findings presented below are supported by more detailed and specific findings in Section VIII of the main report.

- There is a demonstrated need for more ISTF capability as a much cheaper (compared to flight testing) and a more effective approach for certain kinds of testing.

- Although using the improved ACETEF to satisfy Air Force requirements takes advantage of superior Navy expertise, it adds considerable deployment costs and is inconsistent with the AF philosophy of combining ground and flight testing at one location.
- Although the Air Force plan for ECIT is incomplete and ECIT's potential may be difficult to realize within a short period, the long-term advantages both in terms of effectiveness and cost outweigh the risk.

OTHER CONSIDERATIONS

Costs and capabilities were the major considerations in our analysis; however, several other issues should be considered before any decision is made. These other considerations, discussed only briefly here, are covered more thoroughly in Sections VII and VIII of the main paper.

Other Studies. Affordability issues aside, our review of the test requirements provided by the Air Force and the Navy supports the findings of several prior studies that recommend the development of more and better installed systems test facilities.

Project Reliance: The Need to Make It Work. Project Reliance is an initiative designed to promote efficient multi-Service use of Test and Evaluation (T&E) investment and facilities and to eliminate unwarranted duplication of T&E facilities. Recommendations of a Reliance study group's assessment of test support resources highlight the need to upgrade the EC/avionics ground test capabilities at both Patuxent and Edwards. The framework is now in place to begin a coordinated multi-Service approach to improving ISTFs while minimizing potential duplication. This process should be given the opportunity to work.

Availability of Experienced Work Force. Because the ACETEF work force is already experienced, building an expanded capability at Patuxent River would be easier and quicker than starting an essentially new capability at Edwards.

Navy Expertise. The existing capabilities at Patuxent for the ground testing of electronic combat installed systems are second to none. However, even if a new large anechoic chamber were built at Patuxent, the capacity there would be insufficient to meet all of the expected current and future electronic combat system testing needs.

Service-Unique Requirements. ACETEF support of Navy programs may suffer if required to support higher-priority Air Force aircraft programs such as the F-22 over an

extended period. The problem would be particularly acute if the Navy's A-X development program accelerates and the F-22 schedule slips.

Increased Demand for Ground Testing. Experts believe that future demand for ground testing of EC/avionics systems will increase as the complexity and integration of avionics subsystems increases and the need for significant ground testing grows. The AF has a wide variety of aircraft that can benefit from ISTF testing.

Potential to Meet Workload Surges. Even if one ISTF had the capacity to do sufficient work to satisfy critical DoD requirements, there would be value in having two facilities to meet workload surges or to compensate for the catastrophic loss of one facility.

New Defense Acquisition Strategy. Deputy Secretary of Defense Atwood's new approach to Defense acquisition emphasizes technology demonstration and prototype evaluation. Such a policy requires a strong EC/avionics test capability.

Relative Costs of Test Facilities and Weapon Systems. Some duplication of test assets may be appropriate to minimize the cost of weapon system acquisition. A theoretical example would be procuring two $10 million test instrumentation packages in order to prevent production delays costing $100 million. A relatively small test investment may leverage large acquisition investments and significantly reduce overall acquisition costs.

Program Impact. Total acquisition cost, not test facility cost alone, should be optimized. The cost of test and evaluation (T&E) facilities is not a major driver in determining what the best acquisition strategy should be. For a new program such as the F-22, the cost of an interrupted flight test program at Edwards and of extensive deployments to Patuxent risk increasing system acquisition costs substantially.

Potential for Recovery of Test Facility Investment. An opportunity exists to recover test capability investments during peacetime acquisition by avoiding test and schedule delays, reducing requirements for flight testing, and preventing aircraft losses during test and operations. Costs may also be recovered by reducing weapon systems acquisition expenses (e.g., less test flight hours, reduced procurement quantities) or by avoiding many of the software fixes that occur during production and operation.

RESULTS OF THE ANALYSIS

Our analysis shows that the current ACETEF with an additional (intermediate or large) anechoic chamber *and* an upgraded ECIT facility to complement the LAC at Edwards would satisfy 94% of future requirements. The estimated total 20-year costs for providing

that capability is $589 million in constant FY 1992 dollars ($328 million in dollars discounted at 10% per annum). Other, less-costly options are available. One of these alternatives, increasing the number of ACETEF shifts to 2.5 per day, would satisfy less than two-fifths of the stated requirements at a 20-year cost of about half that of building two additional chambers, but would provide no large aircraft ISTF capability.

Of the other two alternatives, building a large anechoic chamber at ACETEF and increasing the number of supporting shifts to four, or developing an upgraded ECIT capability at Edwards while maintaining the 2.5 shifts at ACETEF, the 20-year system costs are approximately the same. However, developing the ECIT capability would satisfy 25% more requirements than building an LAC at ACETEF.

The increase in requirements met and the cost of that increase for each of the alternatives we examined is shown in Table ES-3. The last column shows the cost per unit of additional needs met, a rough measure of effectiveness relative to cost. Note that the trend of this cost per unit of added effectiveness is precisely opposite that of total additive cost. In other words, effectiveness is gained faster in successive alternatives than additional costs would be incurred. The cost per percent of added needs met for Alternative 2 is almost a third higher than for Alternative 3.

Table ES-3. Cost Per Additional Requirement Met

	Description of Alternative	Percent of Needs Met	Increase of Needs Met	Additive Discounted Costs[a]	Cost per Percent of Added Needs Met
0	Baseline ACETEF	22%	0%	$50	NA
1	Provide 2.5 Shifts at ACETEF	36%	14%	$167	$11.9
2	Build LAC at Patuxent with 4-Shift Capacity	57%	35%	$249	$7.1
3	Build ECIT at Edwards (and Alt. 1 ACETEF)	72%	50%	$264	$5.3
4	Build LAC and ECIT (Alt. 2 + Alt. 3)	94%	72%	$328	$4.6

Note: Costs are in millions of FY 1992 dollars discounted at 10% per annum. See Table ES-2 for constant dollars.

[a] Costs include future investments, 20 years of operations, and deployments, using IDA's estimate for F-22 deployment. Discounted costs are at 10% per annum.

As previously observed, fulfilling most of the stated requirements would require a large ACETEF chamber and an upgraded ECIT capability. However, given the declining defense budget and the intense competition for limited resources, affordability is also a major consideration. A more conservative option would be to develop an upgraded ECIT now. This approach would satisfy a large percentage of the requirements, including the new capability to test large aircraft. Even if funds were not fully (and perhaps prematurely)

committed for two large chambers before a clear historical basis or commitment had been established, this alternative would still provide an important hedge against the catastrophic loss at one facility. It would also provide the greatest flexibility by collocating a high-quality installed systems test capability with the flight testing mission at Edwards. It also follows the recommendations of Project Reliance by expanding electronic combat ISTF capabilities at both ACETEF and ECIT. Requirements should continue to be monitored over the next several years to determine if another, larger, anechoic chamber is justified at ACETEF.

In order to make the ECIT alternative competitive in our analysis above, we assumed that the Air Force was willing to invest an estimated $168 million in constant FY 1992 dollars for a true ISTF operation at Edwards AFB, plus additional investments unique to the F-22 (necessary wherever the F-22 is tested). Furthermore, development of a fully functional ECIT capability would have to be planned and executed quickly if it is to be useful for the F-22 development testing.

We suggest that OSD require the Air Force to program and commit to such a program if OSD is to recommend this alternative to the Congress. Moreover, significant savings should accrue if the Air Force uses ACETEF-developed technologies and approaches as is intended with the funding provided by OSD in its CTEIP funding for ACETEF.

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TABLES

I. INTRODUCTION

The Department of Defense (DoD) test community is faced with a declining defense budget and increased competition for limited resources. At the same time, DoD is initiating new acquisition policies and complex new weapons systems that are expected to generate increased test requirements. Eliminating duplicative facilities and consolidating resources is one way to generate budget savings. This paper examines the efficiency and effectiveness of the potential consolidation of Navy and Air Force electronic warfare installed systems test facilities for ground testing of electronic combat/avionics systems.

A. BACKGROUND

Modern electronic combat/avionics systems for aircraft are becoming increasingly complex. To test such systems comprehensively, the DoD is placing increased emphasis on a class of integrated ground test complexes known as installed systems test facilities (ISTFs). Consistent with these trends, the Department of Defense FY 1992 budget request to Congress included $10 million for the Air Force (AF) to start to develop an Electronic Combat Integrated Test (ECIT) capability at the AF Flight Test Center at Edwards Air Force Base (AFB), California. The Senate Appropriations Committee deferred action on the request and eliminated all 1992 funding [1], noting that the expected total ECIT upgrade would cost $250 million and stating that "ECIT is unjustified due to the possibility of substituting a less costly modification to a Navy facility and because firm test requirements for ECIT are lacking." The Committee further directed DoD to compare the cost of modifying the Navy's Air Combat Environment Test and Evaluation Facility (ACETEF) at Patuxent River Naval Air Station (NAS), Maryland, with the cost of upgrading ECIT. The results were to be submitted with the FY 1993 budget request.

Subsequently, the House and Senate Appropriation Conference Committee, in its report of 18 November 1991, also eliminated the $10 million funding request and directed that no other funds be used to support the ECIT upgrade. The Conference Committee further directed that DoD "should review the capabilities of the Navy's Air Combat Environment Test and Evaluation Facility to determine the feasibility of using this facility

for Air Force testing requirements. The Department should provide this review to the House and Senate Appropriations Committees."

B. SCOPE

In response to the congressional request, the Director, Test and Evaluation, asked the Institute for Defense Analyses (IDA) to determine the costs associated with the various ACETEF and ECIT alternatives and to relate those costs and the capabilities they represent to Air Force and Navy requirements. We did not consider other locations or other options, such as moving ACETEF to Edwards AFB or China Lake NAS. IDA was further tasked to use Service estimates to the maximum extent possible. We have followed that tasking while making sensitivity analyses where appropriate. The final result is highly dependent upon three critical parameters: electronic combat/avionics test requirements, the costs and effectiveness achieved by various combinations of installed systems test facilities at Patuxent River NAS and Edwards AFB, and the resulting capabilities to meet the Service requirements.

C. OBJECTIVE

The primary objective of this study was to identify the best ISTF alternative among various ACETEF and ECIT options that might satisfy electronic combat ground testing requirements for installed systems. This task includes assessing both current and planned testing requirements and capabilities and estimating the related costs. The paper specifically addresses costs and effectiveness in terms of available capacity and projected workload.

D. APPROACH

Our approach is based on three interrelated steps. First, we relate existing and planned ISTF test capabilities to future Navy and Air Force workload requirements. Second, we develop alternative packages of ISTF capabilities that meet various levels of test requirements. Third, we assess the relative costs and effectiveness of each of the alternatives.

The Director, Test and Evaluation, requested that IDA use Service-developed electronic combat (EC) test requirements and costs wherever possible. This is the basis of our study, given the complexity and difficulty of the issues. The focus of our approach was on reviewing and assessing Service-provided information for reasonableness, completeness, and consistency. We primarily relied on Service input and kept our own

original estimates to a minimum. In cases where our assessment of risk differs substantially from Service estimates, we added our own estimates to those of the Service by performing sensitivity analyses. Our approach also included the following specific elements:

- We obtained written information from the Navy and Air Force regarding test program installed systems test facility requirements dealing with EC, test program cost estimates, facility EC test capability/cost estimates, and facility upgrade or modification cost estimates.
- We reviewed recent studies on electronic combat testing requirements, facilities, and capabilities.
- We visited the ACETEF and ECIT facilities and discussed Service-provided information. We received additional related briefings and other requested information as required.
- We assessed information, conducted cost sensitivity analyses and reviewed results with Service points of contact.

E. OUTLINE OF THE REPORT

In this paper, we present the marginal (additional) costs and capabilities estimates for the ACETEF and ECIT, our analysis of those estimates and supplementary analyses, and our findings and recommendations resulting from those analyses. Section II establishes the framework for analysis, including descriptions of the test requirements, alternatives to meet those requirements, the types of costs incurred with those alternatives, and other available studies and considerations. Section III provides an overview of the nature of, and test facilities for, testing for electronic combat capability. This overview is intended as background and includes descriptions of the general avionics testing environment, the Navy, Air Force, and DoD approaches to avionic testing, and some of the available government and contractor facilities. The final subsection deals with specific Project Reliance recommendations. Section IV summarizes the principal capabilities of ACETEF and ECIT, differentiating between those that are existing or funded through this fiscal year, those that are programmed and approved but not yet built, and those that are not yet approved.

Section V covers Navy and Air Force testing requirements, including forecasting concerns and current Service estimates, and IDA sensitivity analyses of those estimates. Section VI summarizes the workload in terms of effectiveness and related marginal costs for each of the ACETEF capability alternatives. Costs include new (unsunk) investment in

facilities and equipment, the additional operating costs of new capabilities, and deployment costs associated with the Services' facilities under appropriate alternatives. We also discuss the likely impact on the Navy and Air Force if the Air Force becomes the major ACETEF customer. Section VII describes other considerations that affect EC testing, including Service-unique requirements, future workload, the Project Reliance time horizon, and the possible need for cost effective albeit duplicative facilities. Section VIII presents findings resulting from our analysis of the various ACETEF and ECIT alternatives.

II. FRAMEWORK FOR ANALYSIS

Testing of electronic combat capability and associated avionics (the two are becoming more and more integrated) is a highly technical and increasingly complex process. Comparing capabilities across facilities can be very subjective and controversial even among recognized experts. Estimating future EC requirements is imprecise at best because of acquisition program uncertainty, unknown user demand (perhaps due to a lack of knowledge as to specific EC test capabilities), program schedule uncertainty, and questions as to facility capacity. Because of variations in these parameters, test requirements as well as cost estimates become increasingly imprecise as the projection period expands into the next century.

In establishing the analytical framework for our analysis, we attempted to build a simple but comprehensive structure that would capture needed information and that would reasonably accommodate the uncertainties described above. The framework was designed to measure demands for electronic combat test resources and the alternative sources of supply to meet that demand. We measured and compared demand and supply in order to determine effectiveness and assign costs to the various alternative combinations.

Demand was established by identifying aircraft program EC test needs requiring installed systems test facilities (Section A). The supply of test resources was determined by reviewing each of the ACETEF and ECIT alternatives and measuring how each might satisfy demand. Our analysis focused on the additional costs incurred in acquiring the test resources and was indifferent to the source of funding (institutional or customer) (Section B). We identified the resource requirements involved in EC testing (facility investment, facility operations and test program deployment) and estimated their costs (Section C). We used other relevant work to supplement both Service-provided data and our analysis (Section D).

A. EC TEST REQUIREMENTS

During their acquisition life cycle, individual aircraft programs require varying degrees of development test and evaluation (DT&E) and operational test and evaluation (OT&E). Such testing is performed either in flight or in ground test, at either government

or contractor facilities. The amount of ground testing for electronic combat depends upon the expected use of the aircraft platform, as well as the complexity (magnitude and intricacy) and configuration (integrated versus federated) of the hardware and software. The use of a specific ground facility depends on the test scenario and the size of the aircraft.

This study specifically dealt with installed systems test facilities (ISTFs) and one of their major elements, the anechoic chamber. ISTFs consist of test equipment, threat simulators and stimulators, and automated data processing systems to perform EW ground testing on an aircraft located in an anechoic chamber. Anechoic chambers provide a shielded free-space environment without interference from external electronic emissions (including second-party monitoring). For purposes of this analysis, requirements for electronic combat/avionics ground testing were limited to those for installed systems test facilities that have various laboratories coupled with an anechoic chamber. Sections III and IV describe the above subjects in greater technical detail, while Section V describes the requirements process and provides specific needs by Service and aircraft.

B. ALTERNATIVE SOURCES FOR ISTF TESTING

For this study, we assumed the Air Force and Navy demand for ISTF testing can be satisfied by capabilities represented by various configurations of facilities, equipment, and people through either ACETEF or ECIT. Their potential ISTF capabilities fall into three classifications: (1) the current program (status quo) represents capabilities that already exist or have been budgeted, (2) programmed and approved capabilities consist of planned future capabilities sanctioned in the DoD Future Years Defense Program (FYDP), and (3) other potential capabilities that have not been approved but that are required and reasonable additions within a specific alternative in order to satisfy EC test requirements

Funding can be institutional in the form of Central Test and Evaluation Investment Program (CTEIP) or Improvement and Modernization (I&M) investments. Funding can also be direct, meaning specific enhancements required and funded by individual programs. The category of potential capabilities contains additional capabilities that may be desirable but have not been approved. The ACETEF and ECIT current, approved, and potential capabilities are summarized in Table 1. We also identified the probable sources of funding to ensure that all relevant costs were included.

Using the capability structure and information obtained from the Navy and Air Force, we developed four alternatives for cost and effectiveness analysis: (1) maintaining the current ACETEF with approved improvements and increasing shift capacity to 2.5, (2)

building a large anechoic chamber with both the small and large chambers operating at 2 shifts each, (3) upgrading the large chamber at Edwards AFB to the ECIT configuration and operating it at 2.5 shifts, and (4) doing both Alternatives 2 and 3. Each alternative, related analysis, and results, including several excursions to incorporate sensitivity analyses within each alternative, are presented in Section VI.

Table 1. Current and Planned Capabilities

	ACETEF	ECIT
Current	Small anechoic chamber (SAC), the Aircraft Anechoic Test Facility (AATF)	Benefield Anechoic Facility (BAF) with limited ISTF capability
Approved	Various upgrades through funding of CTEIP, I&M	None, by direction of Congress
Potential	Large anechoic chamber (LAC) through institutional funding	Various ISTF capabilities through institutional and program funding

C. TYPES OF COSTS

Providing necessary test resources such as facilities, materiel, labor, etc., is a function of both the program office customer who generates the demand and the test organization that oversees the entire test supply process. We developed our cost structure to identify the general type of activity being performed and the specific kinds of resources (cost elements) required. This structure was particularly useful in collecting all relevant costs. Specific cost elements were summarized by (1) investment costs to obtain the needed capabilities, (2) operating costs to include additional expenses of running the enhanced test facility, and (3) deployment costs for people and materiel that would be moved to a test location other than that normally used by that Service (i.e., AF programs to Patuxent River NAS, Navy programs to Edwards AFB).

As shown in Table 2, we identified four major types of activities that must be accomplished on every test: (1) the test organization providing basic capability, (2) the test organization providing program-specific facilities and equipment as funded by the program office, (3) the test organization and program personnel developing and performing the actual test, and (4) the test organization supporting the program test (indirect support). The table also shows the major cost elements or resource type being used, e.g., facilities, labor, etc., for each activity by investment, operations and deployment.

All costs are marginal (also referred to as differential or incremental costs) i.e., they are additional costs (change in total costs) that would be incurred when comparing which

investment plan would yield the best results. Costs already incurred for existing resources (e.g., facilities, equipment) were considered to be sunk costs and, accordingly, were not included in the analysis.

Table 2. Primary Cost Structure

	Investment			Operating and Development			
	Facilities	Materiel	Other	Labor	Travel	Materiel	Other
Provide generic test capabilities	X	X	X	X	X	X	X
Provide program-specific investment	X	X	X				
Perform program-specific test				X	X	X	X
Support program-specific test				X	X	X	X

D. OTHER STUDIES AND CONSIDERATIONS

The general subjects of electronic warfare testing, installed test facilities, and anechoic chambers have been studied extensively in recent years in terms of requirements, capabilities, and costs. The information compiled in three major study efforts was particularly relevant and timely. First, the "Final Report on Electronic Warfare Test Capabilities" prepared by the Electronic Warfare Reliance Study Group [3] contained ISTF capabilities and facilities, estimated EC/avionics test requirements (categorized by the size of required anechoic chambers), and included recommendations regarding future growth and lead Service responsibilities.

The Georgia Tech Research Institute (GTRI) study estimated Navy ISTF requirements for the ACETEF facility by type of aircraft for FY 1994 through FY 1996 [7]. Finally, the OSD EW T&E Investment Strategy Panel was formed to develop a coordinated DoD strategy to achieve an acceptable balance in EW test capabilities. The panel consists of representatives from the offices of the Director, Test and Evaluation, the Assistant Secretary of Defense for Command, Control, Communications and Intelligence, and the Director of Operational Test and Evaluation and each of the Services. To date, the panel has issued two reports, which outline the panel's findings and make recommendations to improve the EC testing process [5 and 6]. The study team also reviewed some 50 other documents [7 through 56].

III. ELECTRONIC COMBAT/AVIONICS SYSTEM TESTING

Installed systems test facilities (ISTFs) are complexes of anechoic chambers, automated data processing systems, standard and unique test equipment, threat simulators, and other devices necessary to simulate mission scenarios and stimulate an EC/avionics system installed and integrated in an operationally functional configuration. Over the last decade, the use of ISTFs has grown as their utility has been recognized in trouble-shooting systems under test as well as serving as an integral part of both development test and evaluation and operational test and evaluation. The congressional language that generated this study did not challenge the utility of installed systems test facilities. Nonetheless, we believe that a review of modern EC/avionics system trends and the associated test complexities will facilitate understanding later portions of this study that address test requirements and the cost and effectiveness of alternative approaches.

A. BACKGROUND

1. Trends in Electronic Combat/Avionics Systems

There is a wealth of anecdotal evidence that the complexity of modern avionics systems, as well as the complexity of testing them, is increasing rapidly. From a cost perspective, EC/avionics subsystems represent a growing fraction of the procurement cost of new aircraft—approaching one-third of systems currently in production (see Figure 13 in Section VII). The next generation of aircraft (B-2, F-22, A-X) are expected to continue this trend.

In addition, the complexity of avionics software, as measured by lines of code, is rapidly increasing, with the newest systems requiring over one million lines of code, and the next-generation of systems expected to require even larger software programs (see (Figure 14). Overall, the contribution of avionics systems and software to system effectiveness has grown rapidly, and with it the importance of thorough testing under conditions that stress the system in a fashion representative of the likely operational environment.

A specific example is the F-16 flight test program, shown in Figure 1 from its prototype phase in the mid-1970s. First, note that significant testing continued long after production began in mid-1978. There have been more test flying hours in virtually every year since then than there were in any year prior to the start of production. Second, because of the increasingly complex avionics modifications and upgrades reflected in the block designations along the horizontal axis, the number of test flight hours have moved consistently up. The leveling of hours in the late 1980s can be attributed to the activation of the current F-16 Integrated Facility for Avionics Systems Test (IFAST) capability at Edwards AFB. Testing a current F-16 avionics tape (a software program) can involve almost 1,000 different test information sheets (TISs), each of which represents a set of conditions under which the whole system, with its software, is to be tested one or more times. This compares to several hundred TISs as recently as the mid-1980s.

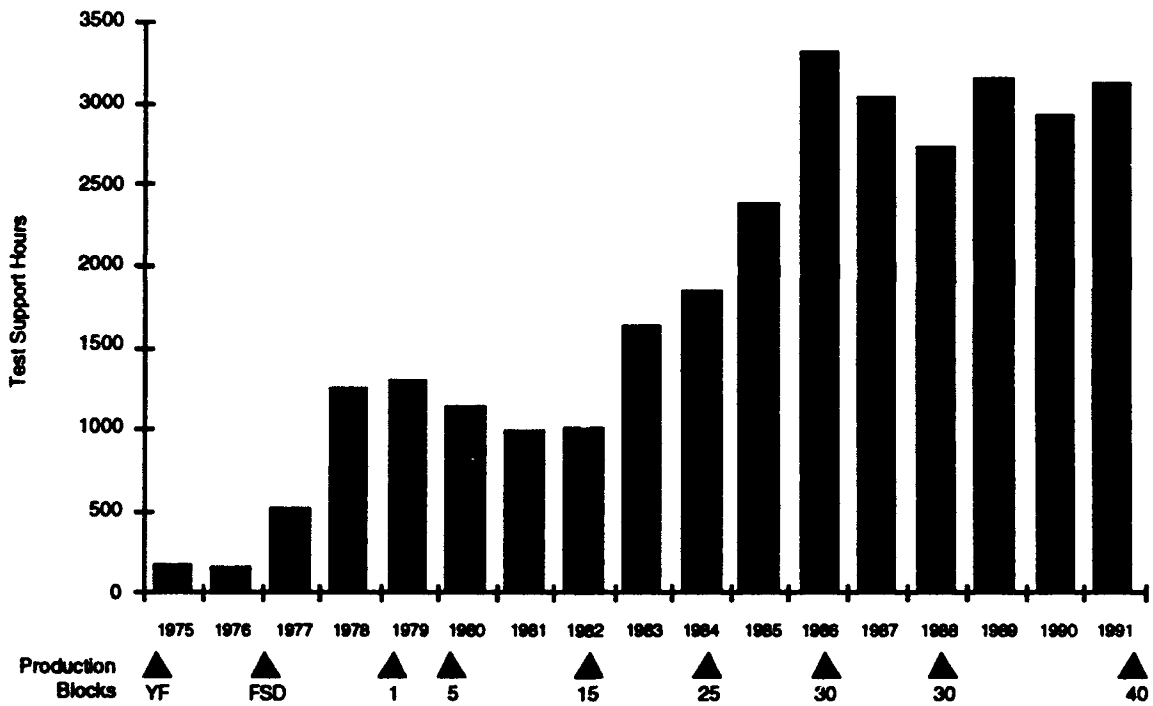

Figure 1. Total F-16 Test Support Flight Time

2. The Trend Toward Highly Integrated Systems

Perhaps more dramatic than the general increase in avionics system hardware and software complexity is the quantum leap in complexity that accompanies the new highly integrated EC/avionics/flight controls/mission computer systems. The F-16 Block 50, the

F-15E, and the MC-130 have already started the trend toward greater integration. The B-2, C-17, F-22, and RH-66 will have the first of the fully integrated EC/avionics/flight controls/mission computer systems. The implications for testing are significant. In the previous generation of largely federated systems, specific functions were performed by individual "black boxes" and software. This permitted individual functions and the subsystems that performed them to be tested in isolation from the rest of the system.

In integrated avionics systems, the various functions are still associated with identifiable "sensors," but the computational process is performed by hardware and software residing in multi-purpose black boxes within the total system. Which black box performs a function changes with the overall demands being placed on the avionics system as a whole. Testing a "subsystem" thus requires that the entire avionics package be operating, with representative simulations stressing the various functions, and with the whole system subjected to some form of simulated mission or operation, whether via flight test or ground test.

3. The Need for a Mix of Flight and Ground Test

The test process ultimately serves an array of objectives. Early in a test program, the emphasis will be placed on getting the system to work. This involves ensuring that the components fit together and generally operate in the intended fashion. Much of this phase is trouble-shooting. Later, the emphasis changes to measuring system performance for selected parameters or characteristics in order to determine compliance with contractual requirements. Overlapping this compliance-oriented testing and continuing into operational employment is testing to determine military effectiveness and suitability, to refine tactics, etc.

Performing all the testing required for modern avionics systems by flight test is simply not achievable. The F-16 Combined Test Force estimated that up to 80% of the test runs (basically, one TIS at a specified set of test conditions) can be performed on the ground. One can imagine how Figure 1 would look in the absence of ground testing.

Overall, the case for ground testing as an adjunct to flight testing, rests on several factors.

- Ground tests can have a cost advantage of between 7 and 15 to 1 over flight test [54]. Greater knowledge about the performance of the system can be gained at lower cost, and probably in less time, with reduced risk to the test

article and the flight crews. More importantly, certain tests that simply are not practical in flight can be performed.

- The complexity and integrated nature of modern avionics systems requires that they be thoroughly checked in a forgiving environment before risking flight test. Only a ground test facility capable of operating the full system under rigorous stresses representative of what the system will see in flight is adequate to perform this pre-flight test activity.
- Modern systems are designed to operate in such a wide array of conditions, with so many operating modes, that testing all via flight test would be prohibitively expensive.
- The information gained from ground test can be used to focus flight test on regimes that will give a thorough evaluation of the system.
- Many aspects of the test process require that large numbers of signals at high data rates be monitored on a near continuous basis. Physical constraints within an aircraft in flight make this almost impossible. The difficulty is compounded by the inability to precisely control, or even measure, environmental conditions in flight. (While eventually the aircraft will need to operate in whatever environment happens to exist, large portions of the flight test program require either a controlled or a known environment so as to evaluate the response of the system to known stimuli.).
- It is often difficult to present sufficient threat or target density on an open air range.
- Finally, security concerns argue against operating certain threat replicas, and "blue" systems responses, on an open air range.

4. The Need for Installed Systems Test Facilities (ISTF)

A wide array of ground test facilities already exist. The IFAST at Edwards AFB, already discussed briefly, is basically a "spread bench" for avionics to be laid out in a fashion that facilitates stimulation of parts of (or all of) the system, and measurement of the system response. However, the system is not installed in the airframe, and many radiating components are not able to be operated in a fully functional configuration. These deficiencies drive the need for ISTF class facilities.

An ISTF, by definition, tests the avionics system in its "installed" configuration. The presence of an anechoic chamber (or, for limited purposes, a shielded hangar) permits radiating elements of the system to radiate without fear of hostile interception. The chamber effectively isolates the system under test from outside radiating sources, which

facilitates relating system responses to known stimuli. Finally, depending upon the test concept, the anechoic chamber may permit use of radiating threat simulators.

ISTFs fall into three categories, based upon the sophistication of the test scenarios and the fidelity of the threat simulators. Based upon definitions taken from the EW Reliance Study Group [3], the categories are defined as follows:

- Category I facilities provide mission-level testing using test article and validated red/blue/gray environments (threat/simulation) with free play (both threat and test article) operators in realistic, large-scale engagements.
- Category II facilities provide platform level testing with free play (test article only) operators in the loop and limited, validated red/blue/gray stimulation in realistic scenarios.
- Category III facilities provide system or subsystem-level testing using minimal, calibrated stimulation of test articles under specific conditions.
- The Reliance Study also identified a fourth category, which provides special-purpose testing. This category includes radar cross-section measurement facilities, antenna pattern measurement facilities, and other facilities that test less than complete avionics systems or limited characteristics of the test article.

B. SERVICE APPROACHES TO TESTING AVIONICS

The two principal facilities under review in this study are two Category II facilities: the programmed Air Combat Environment Test and Evaluation Facility (ACETEF) at Patuxent River NAS, and the proposed Electronic Combat Integrated Test (ECIT) facility at Edwards AFB. To an extent, the actual use of ACETEF, and the proposed use of ECIT, reflect slightly different approaches to avionics systems test. Both the Air Force and the Navy tend to view ground testing as serving two principal roles: (1) it provides a low-risk environment in which to get the system under test "up and running," and (2) it permits the system to be run through its paces throughout its entire performance envelope, serving as a screening device for focusing subsequent flight testing on those portions of the performance envelope perceived as potential problem areas.

Having identified these shared views, however, we also believe that the Navy has tended to view a visit to the ACETEF as a relatively infrequent event for the typical program. Put another way, a system comes to ACETEF prior to significant flight test for a relatively lengthy stay (weeks to months). During this time, the system is thoroughly run through its paces, and every problem that can be identified and fixed on site is fixed. The system then goes into flight test, often at a location remote from Patuxent River. The

system may return to ACETEF at some future point, but these visits are expected to be brief and widely separated in time.

The Air Force, on the other hand, seems to intend to use the ECIT (assuming it is pursued) in a fashion somewhat analogous to the IFAST. Systems arriving for flight test would go to ECIT for as comprehensive testing as possible, with problems fixed along the way. When sufficient confidence has been established in the functionality of the system, flight test would start at the same installation as the ECIT ground test, and supported by many of the same test engineers (both contractor and government). The plan would be for frequent, short returns to the ECIT to "clear" increasingly complex portions of the avionics system for flight test. This approach, theoretically, places a high premium on collocation of the flight test program with the ISTF (in this case, the ECIT).

There are numerous factors that drive these approaches. First, the most extensive threats and threat simulators are located on ranges in the southwest United States, on or near Edwards AFB. The threats of most interest to the Navy are located at China Lake, CA, far away from Patuxent River, MD.

It is not clear that either the Navy or Air Force approach is "right." The approaches appear to reflect historically different methods that have been successfully used by the two Services.

C. AVAILABLE AVIONICS GROUND TEST FACILITIES

For purposes of this study, ground test facilities need an anechoic chamber at least large enough to test a tactical-sized aircraft. For our purposes, we followed the Navy terminology and called this a "small anechoic chamber." (The DoD EW Reliance Study Group calls this size of chamber "intermediate" [3].) In addition, the DoD EW Test and Evaluation Investment Strategy report found that free-space radiation capability in a multi-spectral [electro-optical (EO), infrared (IR), and radio frequency (RF)] facility best addresses the requirements for integrated system test [5]. No existing facility fully satisfies the requirement at this time. However, the ACETEF comes close, and programmed enhancements (i.e., those that are part of an approved FYDP) will bring it closer.

The Preflight Integration of Munitions and Electronic Systems (PRIMES) facility at Eglin AFB represents a significant capability for integration of armament systems with host aircraft and for test of EC systems. However, it does not currently have a significant capability for integrated avionics systems test. In addition, the PRIMES facility was not

included in the congressional language directing this study. We have therefore not considered the PRIMES as a principal candidate for installed EC/avionics systems test.

The current ECIT at Edwards AFB represents a limited capability from an ISTF perspective. With enhancements as described by the Air Force during this study, the facility could achieve a significant capability—comparable to the ACETEF as currently programmed. There are, however, technical risks associated with the approaches proposed by both the Navy and Air Force for enhancing their respective facilities, which are discussed later in this report.

We are aware of only Category III ISTF-class facilities at contractor plants, such as General Dynamics–Fort Worth and Grumman. Most contractors who are heavily involved in EC/avionics work have systems integration laboratories (SILs), which represent a significant "bench integration and test" capability.

D. PROJECT RELIANCE AND THE DOD EC STRATEGY

Project Reliance is an outgrowth of Defense Management Review Directive 922, issued in late 1989, directing changes in management of Defense R&D activities. It is a joint-Service effort, under the direction of the Joint Logistics Commanders Joint Coordinating Group for T&E. The objective of Project Reliance is to eliminate unnecessary duplication while better focusing limited T&E investment funding on improvement and modernization projects that provide the best overall gain in test capability for the DoD.

Reliance reviewed existing ISTF capabilities and projected DoD requirements for such facilities. The conclusions they reached that are relevant to this study were:

- 1.4 Category I, 4.5 Category II, and 3.8 Category III facilities are required. (AECTEF is currently a Category II facility, PRIMES and the possible ECIT are Category III facilities).
- 3.2 large aircraft anechoic chambers are required. (There now is one, with limited ISTF capability.)

The study designated the Navy as lead for ISTFs, and recommended that the Services under Navy leadership develop an ISTF Master Plan. The Reliance study group recommended that the following be considered:

- ACETEF be developed to a Category I level of capability, with an (existing) fighter-sized chamber. Effort on a large chamber should be limited to planning activities, pending clarification of ISTF workload. The current CTEIP

program is working toward this end, with lessons learned to be shared by subsequent developers.

- The ECIT (the Edwards facility, referred to as ECIT in the Reliance study) should be developed into a Category II facility principally supporting new-generation systems. Alternative 3 of this study follows this Reliance recommendation.
- PRIMES should be developed into a Category II facility primarily to support armament integration and test of current-generation systems.

Data submitted by the Services in support of this IDA study reduced the workload from the projected levels used in the Project Reliance study. For example, the AF reduced its projection over 33%. The Service data provided requirements for more ISTF capacity than currently exists, particularly the need for a large chamber. Section V provides details of the ISTF requirements.

IV. ACETEF AND ECIT CAPABILITIES

This section of the report provides a summary of current capabilities at the two facilities that are the primary focus of this study—the Navy's ACETEF, including programmed enhancements;[1] and the Air Force's ECIT as it currently exists.[2] This section also summarizes possible additional enhancements at ACETEF and at ECIT that will provide additional ISTF capacity and capability. Later sections address the costs and benefits of these possible additional enhancements.

A. CURRENT CAPABILITIES

1. Air Combat Environment Test and Evaluation Facility (ACETEF)[3]

The ACETEF is located at the Naval Air Warfare Center, Patuxent River NAS, Maryland [formerly known as the Naval Air Test Center (NATC)]. This organization is generally recognized within the DoD electronic combat/avionics test community as having the broadest experience in developing and using all categories (i.e., I through IV, as discussed earlier) of ISTF/anechoic chambers, especially in the areas of installed systems testing and electromagnetic environmental effects (E^3).[4]

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1 We treated the programmed enhancements as "given" in this study, because they are part of an approved FYDP program and financial plan. Nothing in the congressional committee language initiating this study indicates that Congress questions the programmed ACETEF enhancements.

2 The existing ground test facilities at the Air Force Flight Test Center (AFFTC) consist of the Test and Evaluation Mission Simulator (TEMS), the Integration Facility for Avionics Systems (IFAST), and the Benefield Anechoic Facility (BAF). ECIT is the term applied to these facilities *plus* additional simulation, stimulation, and command and control capabilities. For ease of discussion, we use the term ECIT to describe the facilities now existing at AFFTC, as well as the enhanced facilities discussed later in the section.

3 Most of the description of Navy ground test facilities was taken from an undated NATC pamphlet, "Air Combat Environment Test and Evaluation Facility (ACETEF)," which was distributed during a briefing to the IDA study team (see Reference [2]). This pamphlet discusses Navy ground test from the early 1970s through the current ACETEF concept.

4 Based on narrative included in Reference [3], p 33.

a. General Description

The origins of the Navy's ground test facility program can be traced to the 1970s, when the then NATC developed six largely autonomous simulation/stimulation laboratories for ground test of aircraft subsystems and systems. The laboratories were intended to support flight test by ground testing the systems throughout as much of their performance envelope as possible. The laboratories were:

- Tactical Avionics Software Test and Evaluation Facility (TASTEF). Through simulation and hardware-in-the-loop, TASTEF allows engineers to evaluate core avionics hardware and software in a controlled ground environment.
- Electronic Warfare Integrated Systems Test Laboratory (EWISTL). This permits radio frequency (RF) stimulation of EC equipment through interfaces at the antennae. EWISTL can simulate 1,024 radar emitters with pulse densities of 4 million pulses per second.
- Aircrew Systems Evaluation Facility (ASEF). This primarily focuses on controls and displays and is used to evaluate the man-machine interface.
- Antenna Test Laboratory Automated System (ATLAS). ATLAS provides the capability to develop antenna pattern data from aircraft flight data. The data is used by RF generating facilities to model antenna effects when the system is stimulated by signal injection behind the antenna.
- Navy Identification Friend or Foe Test and Evaluation (NIFFTE). This is a hardware-in-the-loop facility for testing identification friend or foe (IFF) subsystems.
- Electromagnetic Environment Generating System (EMEGS). This facility simulates 32 high-powered emitters to simulate the electromagnetic environment on the deck of an aircraft carrier.

By the early 1980s, examination of critical test and evaluation issues led the Navy to the conclusion that significant changes were needed in its approach to ground test. The issues were test realism, threat realism (both density and fidelity), security, increasingly integrated test articles, interoperability (among systems), and cost/complexity of the test articles as well as the test facilities. The result of this examination was development of the ACETEF program, shown conceptually in Figure 2, which will be achieved over a period of time as funding allows.

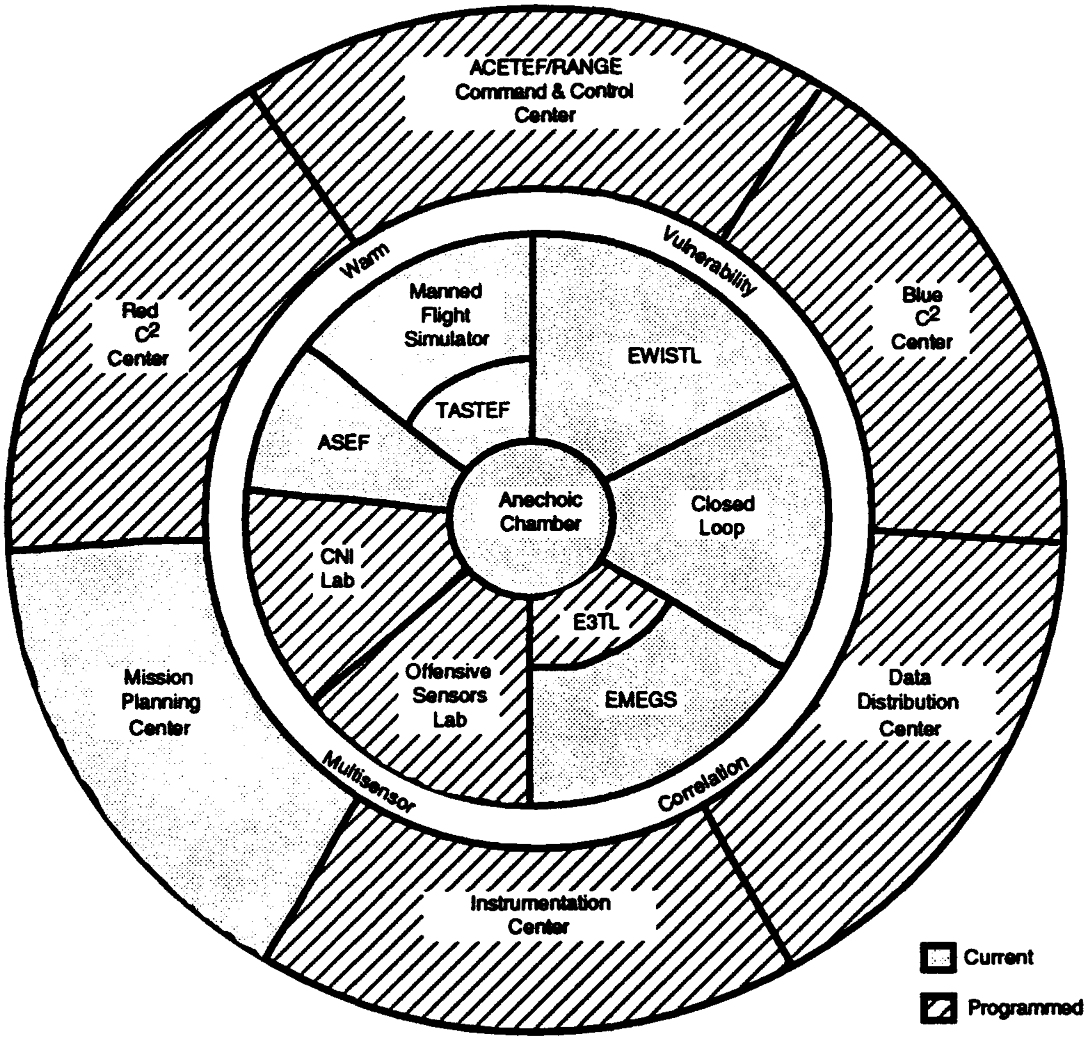

Figure 2. ACETEF Program

ACETEF achieved an initial capability in 1983, when the anechoic chamber was placed into operation. The chamber is 60 feet wide by 100 feet long by 40 feet high.[5] It has a 30-ton crane in the ceiling, has a 40 foot (width) by 20 foot (height) door, and provides 120 decibels of isolation. Any aircraft system except the propulsion system can be operated within the chamber. The current ACETEF also better integrates and coordinates the laboratories that already existed, and provides the following additional capabilities:

- A closed-loop facility provides an RF threat simulator/stimulator capability; that is, the threat simulator responds to the countermeasures taken by the system under test.

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[5] In the terms used in this study, the chamber is a "small" one, suitable for testing tactical-sized aircraft.

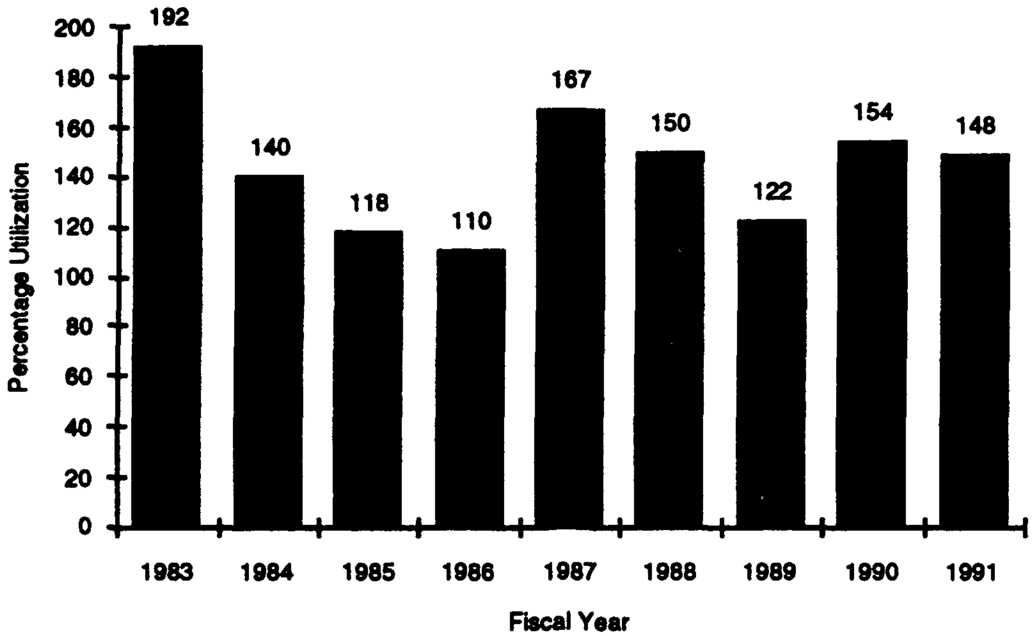
- The EMEGS has been upgraded to the Electromagnetic Environmental Effects Test Laboratory (E^3TL) to provide higher power levels and more emitters.
- EWISTL is being upgraded to increase the number and types of emitters, expand the frequency range, and extend its interface capabilities.
- The TASTEF has been upgraded to provide a Manned Flight Simulator that puts the aircrew (as opposed to test engineer) in the loop.
- A variety of other upgrades have occurred to the Mission Planning Center and other elements of the facility.

Overall, the ACETEF capability represents the most comprehensive ISTF currently in existence. However, the size of the chamber, and its door, limit the facility to tactical-sized aircraft. Further, the size of the chamber would appear to limit stimulation methodology to signal injection and/or the use of "antenna hats." Free-space, far-field radiation is not possible. The relevance of these limitations is discussed in Appendix G.

b. ACETEF Current Usage

ACETEF usage has generally increased since the activation of the anechoic chamber in 1983. The anechoic chamber is currently the "limiting resource"—that is, from a facility point of view, the total throughput of test work at ACETEF is primarily limited by the availability of chamber time. The chamber has been used more than one shift per day since the mid-1980s, and recently has averaged about 1.5 shifts per day on the basis of a 5-day work week (see Figure 3). When the chamber is being used, generally at least one supporting laboratory will also be needed. The actual number of supporting labs used will depend upon the complexity and degree of integration of the system under test, as well as the complexity of the test objectives associated with the specific test run. At this time, the ACETEF can generally support more than one customer at a time. (In fact, on one day of the study team's visit, the manned flight simulator, the aircrew systems evaluation facility, and the anechoic chamber were all in use for three different test programs.)

Generally, ACETEF's workload has consisted of test programs for new and/or upgraded subsystems installed in aircraft that are already operational. No new development aircraft have undergone testing at ACETEF. The Navy also indicated that, with maintenance considerations, facility use could be expanded to a maximum of 2.5 shifts per day.



Notes: Data for 1983 were for only part of the year. Percentage utilization equals the number of 8-hour shifts per 250 work days.

Figure 3. ACETEF Workload

2. The Electronic Combat Integrated Test Facility (ECIT)

The ECIT is located at the Air Force Flight Test Center (AFFTC), Edwards Air Force Base, California. AFFTC is the Air Force's principal facility for aircraft fight test. The ECIT was proposed in the FY 1992 President's Budget request for initiation of a major investment program to bring the existing facilities up to the level of an installed systems test facility. Congress denied the request, and required that the issue of ECIT cost effectiveness, compared to that achieved by additional investment at ACETEF, be reviewed and reported to the appropriations committees.

a. General Description[6]

The use of ground test to support flight test at AFFTC can be traced to the 1950s, when analog simulations supported the X-2 and Dynosoar programs. The current facilities were largely activated during the 1980s, and consist of three principal elements:

- The Test and Evaluation Mission Simulator (TEMS). The TEMS provides real-time piloted simulations of flight dynamics and aircraft systems. A test station typically includes a cockpit, with "out the window" scene generation,

[6] Much of the material in this section was derived from Reference [31].

driven by a digital simulation of aerodynamics, propulsion, flight controls and overall flying qualities. Various mission simulators have been in use since the 1950s. Current simulations include the F-4E, F-5F, Space Shuttle, F-15A-E, F-16A/C, A-7D/YA-7F, B-1B, and several others. The simulators do not provide base motion, and the scene generation is rudimentary compared to that found in contractor man-in-the-loop simulators, Air Force laboratories, or the Navy's ACETEF.

- The Integrated Facility for Avionics Systems Test (IFAST). The IFAST provides avionics "spread bench" test capability for functional verification, anomaly characterization, integration testing, software evaluation, and aircrew/flight test engineer familiarization. The IFAST was first available for use in November 1982, and reached its current configuration in December 1988. The facility contains seven program test areas of about 7000 square feet, of which 6 have 2,800-square-foot shielded bays with an outside field of view, permitting operation of an attack radar, for example. Basically, however, the IFAST provides space, power, and other utility services only; any capability for simulation or stimulation to the test article is determined by what the test program decides to put into the IFAST. For example, the F-16 occupies two bays, and has equipped both an Integrated Avionics Test Station (INATS) and a Radar Test System (RTS). Overall, the F-16 represents the most significant capability now at IFAST, and its use has helped to significantly reduce flying hours, as discussed in Section III.

  However, there are inherent limitations in the IFAST. The test article is not "installed," so that the geometric configuration and cable runs are not necessarily representative of the installed configuration, and effects of airframe and/or propulsion components on the avionics are not represented. Also, there are significant limitations on the ability to use radiating elements of the system under test.

- The Benefield Anechoic Facility (BAF). The BAF is a large anechoic facility, located near the IFAST. It provides a controlled electromagnetic environment in which a test article or system can be stimulated and its responses recorded and analyzed. The chamber size is 264 feet (length) by 250 feet (width) by 70 feet (height), with a door 200 feet (width) by 68 feet (height). The chamber is large enough to test large aircraft (B-52, B-1B, B-2, C-17, C-130, E-6, etc.) or "formations" of up to several tactical aircraft; and is theoretically large enough to permit actual radiation by threat simulators through (far field) free space to stimulate the system under test.[7] The chamber has an 80-foot-diameter turntable, capable of rotating a 250,000-pound load. This permits changing the angle of arrival of signals transmitted from three radiating threat sites located at 120-degree intervals. One site is equipped with a threat

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7 The merits of this approach (free space radiation, as opposed to signal injection) are somewhat disputed within the technical community, as is the suitability of the BAF design to support such a test stimulation methodology. This issue is discussed in greater depth in Appendix G.

generator capable of modeling 256 simultaneous background threats. The other sites have very limited background threat-generation capability. Finally, an 80,000-pound hoist is being installed in the ceiling of the BAF. The BAF was originally built in June 1989 as part of the B-1B program, and turned over to AFFTC as a generic test facility in September 1990. When the chamber was initially activated to support B-1B defensive avionics testing, the threat-generation capability was limited to four (of eleven) "Top-11" threats. The threat-generation capability has subsequently matured so that a higher overall threat density and all 11 of the "Top-11" threats can be generated. However, the BAF can generate neither the density nor the number of specific, high-priority threats that the ACETEF can provide, nor is there any "closed loop" threat capability. Finally, the BAF lacks the simulation, simulation, and command and control capabilities necessary to be a truly useful facility.

Overall, the ECIT capability is not comparable to that which exists today at ACETEF. Among other issues, the three facilities at AFFTC are not generally integrated—that is, an aircrew member in the TEMS cannot "fly" (or fly against) the avionics package in the IFAST, nor can the simulators and stimulators in the IFAST provide signals to an aircraft in the BAF.[8]

b. ECIT Current Usage

While the IFAST is used productively to support ongoing tests, the BAF is of limited utility. FY 1991 data extracted from the Range Utilization Measurement System (RUMS) indicates that each IFAST test area currently occupied is in use about one shift per day, 5 days per week. If workload required it, and funding were available, IFAST utilization would be increased to about 2 shifts per day per test area. The BAF is used about 50% of a shift, although much of the BAF use to date has been for chamber characterization and aircraft "fit" checks. The capacity of the BAF is currently limited to one shift per day, based on manpower and workload, although a limited surge capability to 2 shifts a day is possible. Inherently, the chamber capacity is 2 to 2.5 shifts per day, but additional personnel would be required. The TEMS has been operating at about 20% of capacity recently—but the nature of this facility is such that its heaviest use should be expected when wholly new aircraft or major model changes occur, events which have not occurred recently.

8 The TEMS and IFAST were integrated in 1991 for demonstration purposes. The F-16 Block 40 INATS and an F-15 TEMS crew station were connected in "real-time." However, this sort of integration is not the norm.

Fundamentally, the only portion of the ECIT that represents a significant, current capability is the IFAST, and it is heavily used. The remainder of the ECIT is of limited use unless additional investment occurs to better integrate the existing facilities, and to broaden the simulation, stimulation, and command and control capabilities.

B. PROGRAMMED AND APPROVED CAPABILITIES

1. ACETEF[9]

The current ACETEF program represents cumulative expenditures of about $250 million through FY 1992. About $80 million in additional work has been approved and is programmed in the FYDP to bring the ACETEF to its mature configuration. Table 3 summarizes the funding associated with the program. The paragraphs below provide a brief narrative of the approved enhancements.

Table 3. ACETEF Current and Planned Plant Investment Value

	1989 and Before	1990	1991	1992	1993	1994	To Complete
Military Construction (MILCON)							
RF-shielded hangar	$86.3[a]						
Small anechoic chamber	18.3[a]						
Closed loop	1.0						
Manned flight simulator	4.5						
Aircraft systems lab		12.3					
Night combat test lab						14.7	
Subtotal	$110.1	$12.3	$0.0	$0.0	$0.0	$14.7	$0.0
Laboratory							
Direct project support	$28.2	$2.0	$1.0	$1.0	$1.5	$1.5	$1.5
I&M	37.5	3.6	1.2	1.1	1.5	1.5	1.5
CTEIP		9.15	9.6	13.5	15.1	17.6	23.0
Other	17.2	1.0	1.0				
Subtotal	$82.9	$15.75	$12.8	$15.6	$18.1	$20.6	$26.5
Total	$193.0	$28.05	$12.8	$15.6	$18.1	$35.3	$26.5
Cumulative total	$193.0	$221.05	$233.85	$249.45	$267.55	$302.85	$329.35

Note: All values represent actual past or planned investment in millions of FY 1992 dollars, unless otherwise noted.

[a] Current replacement value.

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9 In addition to the source previously identified, descriptive material on the enhancements has been taken from Reference [10].

A multi-player environment will be provided by completing the outer ring of Figure 2. The Operations and Control Center will provide simulation and control for multi-player, multi-laboratory test scenarios via its range command and control center and red and blue command and control centers. Up to 15 associate players are provided via mini-crew stations. Enhanced software capabilities will provide improved threat generation and control known as Simulated Warfare Environment Generator (SWEG).

The Manned Flight Simulator will be modified to enhance visual, motion, and aural cues provided to aircrew members in high-fidelity cockpit replicas located physically away from the chamber, but integrated with the system under test.

Modifications to EWISTL will provide portable and millimeter-wave, open-loop simulators, jammer simulators, communications environment simulation, additional background threats, and missile launch simulation.

An Offensive Sensors Laboratory (OSL) will provide a capability to generate multi-spectral targets for offensive sensors such as forward looking infrared (FLIR), infrared search and track (IRST), radar, laser sensors, and sensors associated with smart munitions.

The NIFFTE will be modified to a communications, navigation and identification (CNI) laboratory by providing RF simulation of the friendly, foreign, and hostile CNI environment; and to provide a CNI hardware-in-the-loop capability.

The EMEGS is to be upgraded to the E^3TL by increasing power output and adding emitters. Additional enhancements will improve the capabilities of the Aircrew Systems Evaluation Facility and the closed-loop simulator.

The mature ACETEF will represent a significant installed systems test capability. It is not, however, without limitations. Although a second, larger anechoic chamber was under consideration at one time, it is not currently part of an approved, funded program. This limits use of ACETEF to tactical-sized aircraft, and generally to one aircraft at a time in the chamber. Large aircraft testing and multi-aircraft testing are not possible in the chamber, although the shielded hangar at ACETEF affords a limited capability. In addition, the principal methods of stimulation of aircraft systems are through signal injection downstream of the antenna, or via "antenna hats" that mount directly on the antenna. Actual radiation of signals through "free space" is not generally possible, at least in part due to the size of the anechoic chamber. The significance of this is a point of contention within the EC/avionics test community, and is discussed in Appendix G.

Finally, the closed-loop capability available at ACETEF is oriented toward sea-based threats, and is of less value in measuring the performance of systems under test against land-based threats. In addition, from the perspective of the system under test, threats from the closed-loop simulator constitute only a few of the hundreds of threats generated in the overall test scenario. Notwithstanding these limitations, ACETEF represents the only significant closed-loop capability currently available in an ISTF configuration, and, with programmed enhancements, will be the only DoD Category I facility.

2. ECIT

For purposes of this discussion, we have treated the ECIT as having no currently approved enhancements. The ECIT was included in the FY 1992-97 FYDP, which supports the FY1992 President's Budget with approved funding of $10 million per year in T&E investment program elements for a total of $60 million through the end of the FYDP. The Air Force provided information during this study that indicated that this funding paid for only limited enhancements to the ECIT, and that additional funding by customer programs was required if a significant installed systems test capability were to be provided. Congress disapproved the $10 million in FY 1992 funds, and the Office of the Secretary of Defense (OSD) removed the FY 1993 funds from the FY 1993 President's Budget. At this time, the Air Force Program Objective Memorandum (POM) is thought to contain $10 million per year in FY 1994-97, pending the outcome of the OSD study directed by Congress. A detailed discussion of the ECIT cost and funding estimates can be found in Appendix A. Additional enhancements that could be undertaken at ECIT are discussed in the next subsection, but to our knowledge they are not part of an approved, funded Air Force program at this time.

C. POSSIBLE ENHANCEMENTS (NOT APPROVED)

Previously in this section, we mentioned that ACETEF is currently limited to tactical-sized aircraft, although some testing of less stressing test scenarios is possible in the ACETEF shielded hangar. This precludes the testing of many aircraft (e.g., CV-22, C-130, P-3, Joint Stars, E-2C, E-6, F/EF-111, B-1B, B-2) and tests of multiple tactical aircraft operating simultaneously, a stated Navy and Air Force requirement. In addition, the current ACETEF closed-loop capability does not cover all Air Force threat requirements. The current ECIT represents a very limited installed system test capability. Enhancements, beyond those that are currently approved, are possible at either or both

locations. An additional, larger chamber at ACETEF would alleviate some of the limitations there; and also would present opportunities for increasing the total throughput (or capacity) of ACETEF, if necessary or desired. As an alternative, improved simulation, stimulation, and command and control capabilities could be added to ECIT to improve its overall capability. These enhancements are described below.

1. ACETEF

The Navy has considered the possibility of building a second, large[10] anechoic chamber at ACETEF. Although no definitive design had been selected at the time the proposal was shelved, the preliminary design called for a chamber that would be 200 feet (width) by 185 feet (length) by 60 feet (height). This would provide a large aircraft test capability, but would provide little capability to test multi-aircraft formations. Also, that size of chamber would not support free-space, far-field testing, largely limiting tests to the Navy approach of signal injection and "antenna hats."[11] The additional chamber would permit an increase in throughput, from 2.5 shifts per day currently possible, to about 4 shifts per day. Achieving this added capacity would require some modest, but at this time undefined additional laboratory capacity to stimulate and simulate the two chambers. The cost of a second chamber and the degree to which it would satisfy additional test requirements are addressed in Section VI of this report.

Additional closed-loop simulation capability, more representative of land-based threats, will be needed if ACETEF is to be useful for EC testing of Air Force systems. However, this requirement, and the cost of satisfying it, is common to both ACETEF and ECIT. Consequently, its cost was not further considered in this study.

2. ECIT with Additional Simulation and Stimulation Capabilities[12]

The ECIT requires additional simulation, stimulation and command and control capability to be an installed systems test facility. The AFFTC briefed the study team on the enhancements that had been under consideration in earlier ECIT program phases. The most capable system was termed the "vision," a level of capability for which the Air Force now

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[10] If we use the terminology of the Reliance Report [3], the chamber most recently under serious consideration by the Navy would fall into the "intermediate" size category, However, in this study, we have adopted the convention of "small" and "large" only.

[11] The Air Force believes that at least some free space radiation testing will be necessary to test EC/avionics systems in the future.

[12] Much of the information in this section is drawn from Reference [23 through 25].

says there is no requirement. The vision enhancements are grouped in "clusters," as shown in Figure 4, and together would bring ECIT up to a Category 1 level facility. Funding constraints caused the program to be limited conceptually to creation of an improved facility infrastructure, for which $60 million was approved in the FYDP. Additional enhancements were viewed by the AF as "to be built, when and if needed." Although not explicitly so stated, the clear implication is that the customer program with the need would be expected to finance the enhancements, consistent with a specified ECIT architecture.

The basic ($60 million) infrastructure enhancement was to be the "anechoic cluster," depicted in Figure 5. The cluster would provide standard interfaces between a (new) control center and TEMS, IFAST, and the chamber. It also would provide upgrades to the facility operations and control center; would improve the simulation and test control capability by providing better scenario generation and control; and would enhance the RF threat-generation capability. Although approved funding was $60 million, the estimated cost is about $72 million.

To describe this infrastructure enhancement in greater detail, and to relate it to the most stringent, known test requirement (the F-22), it is necessary to depart from the "cluster" description of the Air Force ECIT vision, and instead refer to an alternative "building block" approach, also used by the Air Force to define potential enhancements. The building block approach is shown in Figure 6. The infrastructure improvements all affect the two bottom rows and are unshaded. The capabilities of the infrastructure blocks are [28]:

- Intrafacility Communication—provides the communications network within the ECIT for digital, video, and voice signals.
- Test Direction and Conduct—provides the hardware and software for conducting tests, and provides consoles and stations to the test director and the test conductor.
- Timing and Control—provides synchronization and control of system computers and other hardware during a test.
- Data Collection and Analysis—provides collection of data from the system under test and from chamber environment; provides for display, processing, and storage of the data; collects data at frequencies from DC to 18 GHz and at rate of 1 to 10 Mbits/sec.
- Engineering Support—provides test development system support tools.

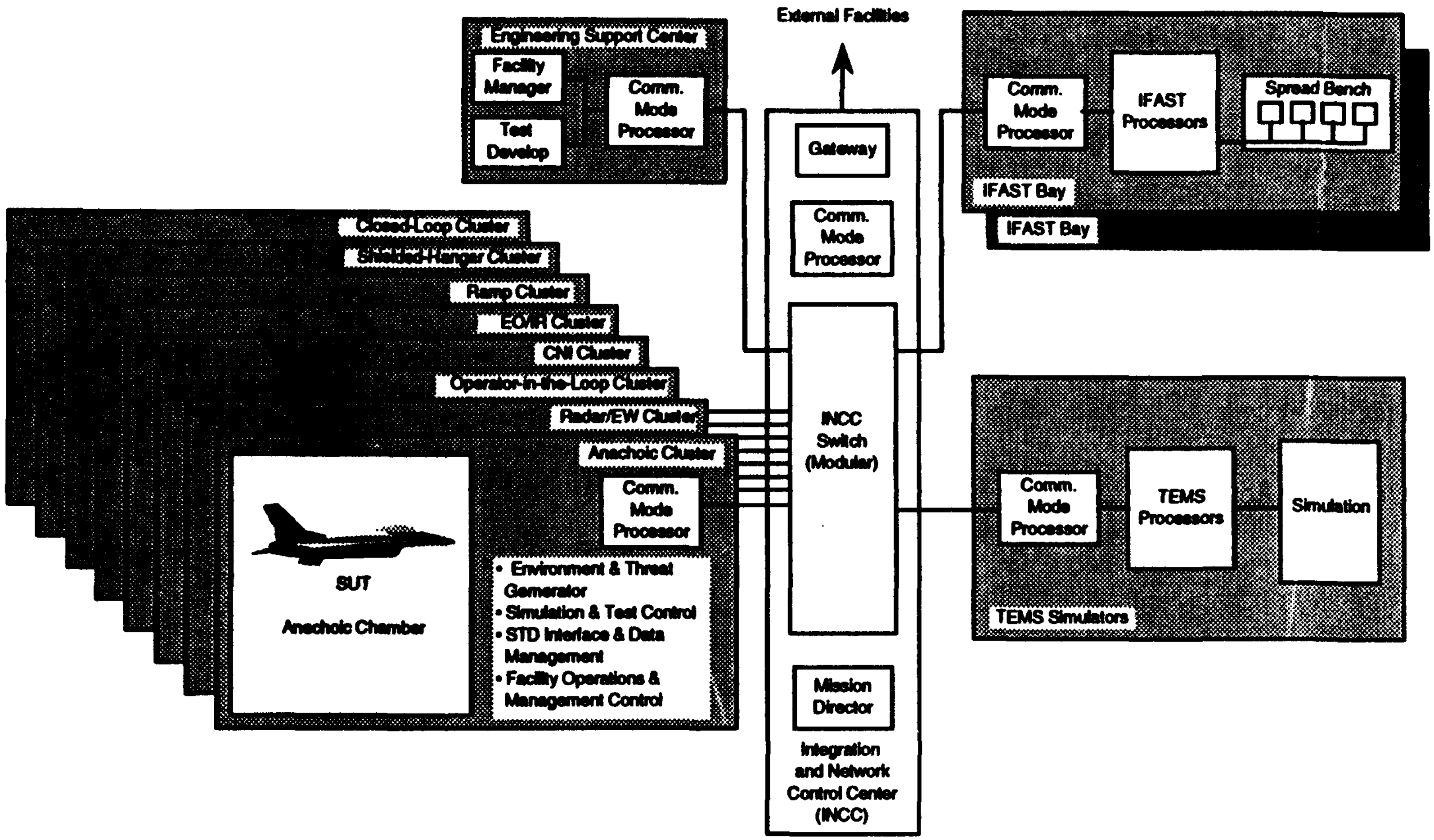


Figure 4. ECIT Architecture: The "Vision"

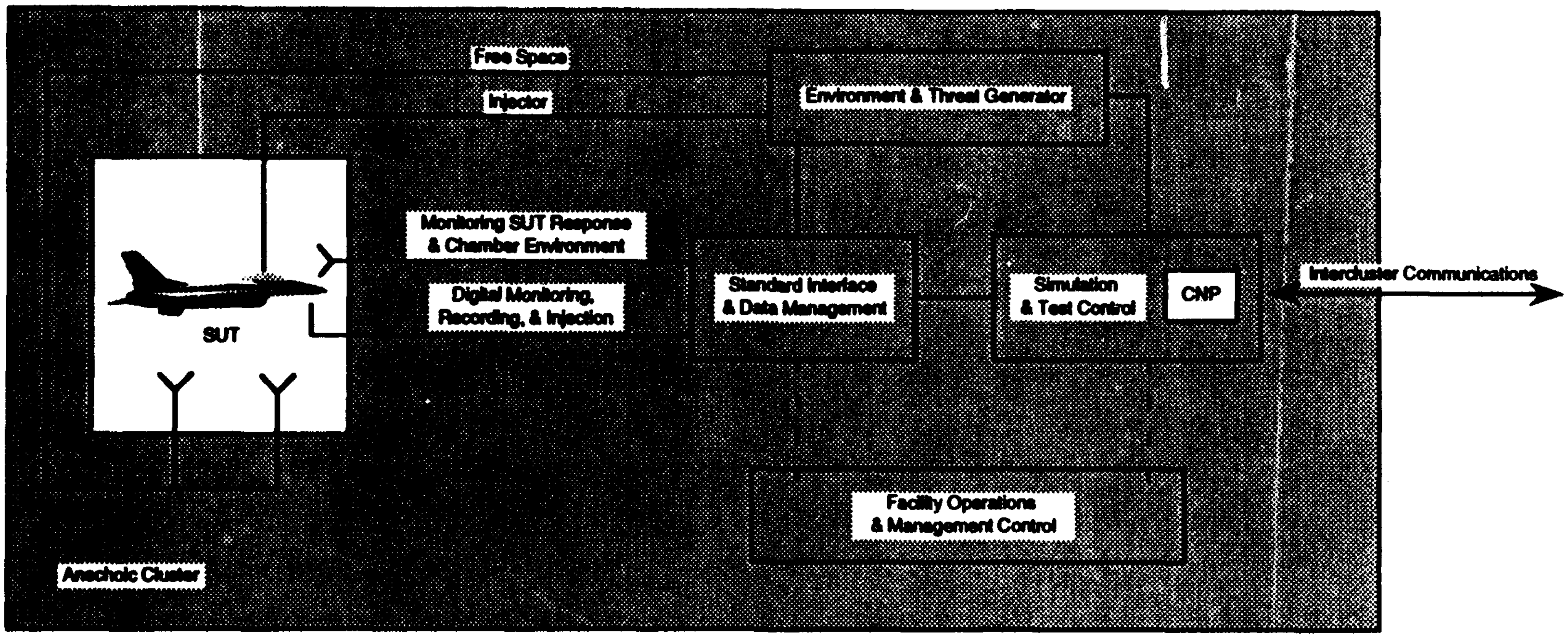


Figure 5. Anechoic Cluster: The Basic Infrastructure

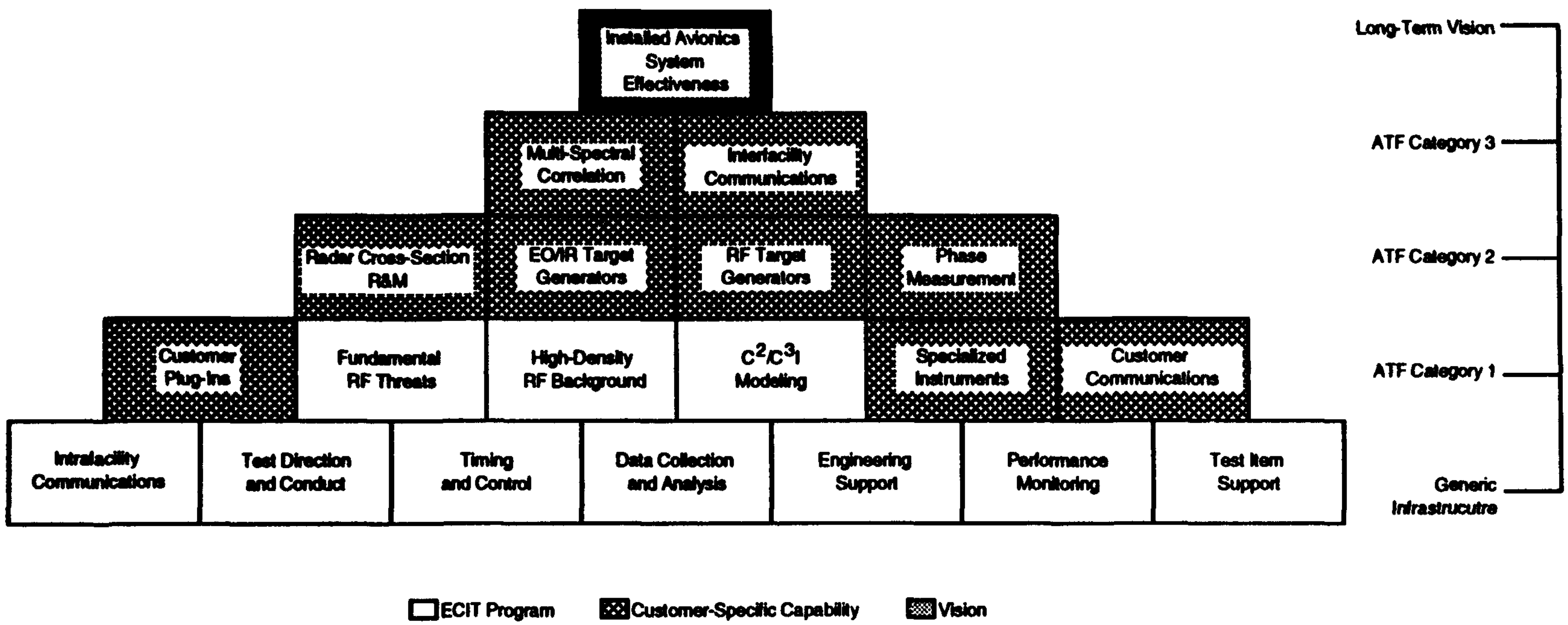


Figure 6. Building Block Approach

- Performance Monitoring—provides the ability to monitor the performance of the ECIT itself, and the validity of the test setup.
- Test Item Support—provides cooling air, hydraulics, electrical power, etc., to the system under test.
- Fundamental RF Threats—provides specific threat replica stimulation's to the system under test. The threats provided here are described by the Air Force as those needed for initial F-22 testing as well as most other fighter and bomber tests, and include surface-to-air, air-to-air, friendly, hostile, and other RF sources.
- High-Density RF Background—provides the overall RF density representative of the theater of operation, and upon which the fundamental RF threats outlined above are superimposed. Overall objective is a density of greater than 10 million pulses per second.
- C^2/C^3I Modeling—provides the command, control and communications for the environment of the fundamental RF threats and the background C^3 density representative of the RF background.

The above capabilities are all within the $60 million proposed program. However, the F-22 minimum facility requirements, based on information provided during our visit, are the three bottom rows of Figure 6, designated as ATF Category 2. Using the building block definitions, the additional capabilities required are:

- Customer Plug-ins—provide unique RF threats and targets the test program desires for the test environment.
- Specialized Instrumentation—any instrumentation needed to satisfy unusual requirements of the test customer.
- Customer Communications—provides special links for customer off-site data networks and links to other AFFTC test facilities.
- Radar Cross-Section R&M—provides the ability to assess the reliability and maintainability (R&M) of near-field radar cross-section (RCS) of the test article.
- EO/IR Target Generator—provides targets for offensive sensors operating in the EO/IR frequency bands.
- RF Target Generator—provides RF targets for the radar.
- Phase measurement—provides the capability to test phase interferometer systems.

There is no easy way to "map" these blocks to either the clusters shown earlier in the ECIT vision, or to the capabilities previously discussed in the Navy's ACETEF. In a

general sense, the additional blocks correlate to the ACETEF Offensive Sensors Laboratory, EWISTL, CNI laboratory, Advanced Flight Simulator, and the Operations and Control Center. Not provided at this level of investment is either the ability to correlate multispectral threats and targets, or the ability to link with other DoD test facilities.

The net result of all the potential ECIT enhancements discussed in this section would be a Category II ISTF capability roughly equal to that expected to be available at ACETEF upon completion of approved ACETEF upgrades, except as follows:

- The ECIT would provide a large chamber capability.
- The ECIT threats, communications background, and targets would be more "land-based" than "sea-based."
- There would not be a closed-loop capability.
- There would continue to exist differences in philosophy and test methods in the areas of signal injection versus free-space, far-field radiation. Only ECIT would have the potential for both free-space, far-field signal radiation and injection.

The estimated cost of facility upgrades to the ECIT are presented in Section VI.

V. REQUIREMENTS

The purpose of this section is to discuss the requirements for testing at ACETEF and ECIT facilities. It starts with a discussion of some of the uncertainties associated with attempting to forecast future electronic combat testing needs, and the risks if testing is not done. This is followed by descriptions and tables of the Navy and AF test requirement submissions. The final subsection discusses how IDA used this information.

A. FORECASTING DIFFICULTIES

We asked the Navy and the Air Force to project their anechoic chamber/ISTF requirements for FY 1995 through 2005. The Navy provided forecasts only from FY 1994 through FY 1996. These data were in some detail, broken out by requirements for the Aircraft Anechoic Test Facility (AATF), a small anechoic chamber, and for a large anechoic chamber, as well as historical usage data for the AATF, but no information for the other outyears of interest. The Air Force projected potential average annual usage over the next 18 years (FY 1992-2009) of *electronic combat installed systems* test facilities, by aircraft program. There is no breakout by year for this information.

The Major Range and Test Facility Base (MRTFB) installations, including Patuxent River NAS and Edwards AFB, routinely project future requirements for their facilities. The installation planners use specifics gleaned from discussions with weapon system program offices and other users. They generally factor up the program office estimates based on their experience with specific test facility usage. They do so because program offices often do not confirm expected use early enough for planning, and because program estimates are usually low. Two principal reasons for program offices making low usage estimates are: (1) optimism in forecasting uncertain requirements for specific tests, and (2) the program office's perception that it may be forced to buy a test capability that it needs but which is not currently available.

As to the first, program offices manage their programs to budgets that are sensitive to program schedule. The goal of the program is to get in and out of testing in the minimum time consistent with achieving the test goals. This optimism may cause an underestimate of the time in test. Each new program expects to have solved, prior to

testing, problems that plagued earlier programs. But new, unforeseen difficulties often arise that require other testing. Program offices do not want to lose flexibility by tying their programs to specific test scenarios that may or may not come to pass.

Secondly, program offices usually fund program-specific facility requirements on test installations. [For generic capabilities, the installation initiates its own requirements through Improvement and Modernization (I&M) and Military Construction (MILCON) funding. Requirements for multi-Service national test assets may be met through the OSD-administered Central Test and Evaluation Investment Program (CTEIP)]. Stating a need for an unavailable test capability may result in the program office being required to fund the facility that provides it.

Complicating the problem for independent analysis is that many of the systems of interest in electronic combat/avionics test programs are classified. Thus, we had little opportunity to independently check the reasonableness of Service test requirements estimates. Instead, we compared future projections with needs met and unmet by the same or similar aircraft programs in the past. These analogies gave us confidence that the future needs were reasonable.

Moreover, the complexity of avionics and enhancements to test capability are evolving rapidly. Control of avionics processing is changing from "federated" to "federated with communication" to partially (and, eventually, fully) "integrated" systems (see Section III). No one yet knows how to test, much less how much testing will be required for a completely integrated EC/avionics system. (Because of this increasing interconnectivity and integration, we use the convention "EC/avionics" to describe the installed systems being tested in the anechoic chamber.)

B. RISKS

In their discussions with IDA, both facility and program office personnel made it clear that there are always tradeoffs between levels of testing, availability of satisfactory test facilities, cost, and schedule on one hand, and risk to mission performance and safety on the other. Some things cannot be tested because there is no acceptable way to test them. Others are not tested to the fullest because it is simply too costly for the marginal value received. Program managers and testers routinely make judgments as to how much risk they are willing to accept to keep a program on cost and schedule. In that sense, test "requirements" should not be considered absolute. Still, it is usually more expensive to

correct installed avionics errors in production than to discover and correct the error during development.

C. NAVY REQUIREMENTS FOR ACETEF

Figure 7 shows the Navy projections for FY 1994 through FY 1996 for Navy systems expected to use the capabilities of ACETEF through either the Shielded Hangar, the current small anechoic chamber (SAC), or a postulated large anechoic chamber (LAC) at Patuxent River NAS. It does not include anticipated usage by the Army, Coast Guard, Air Force, or foreign customers. The Army's RH-66 helicopter could become a major customer in the future because it has integrated avionics and is expected to be tested at ACETEF.

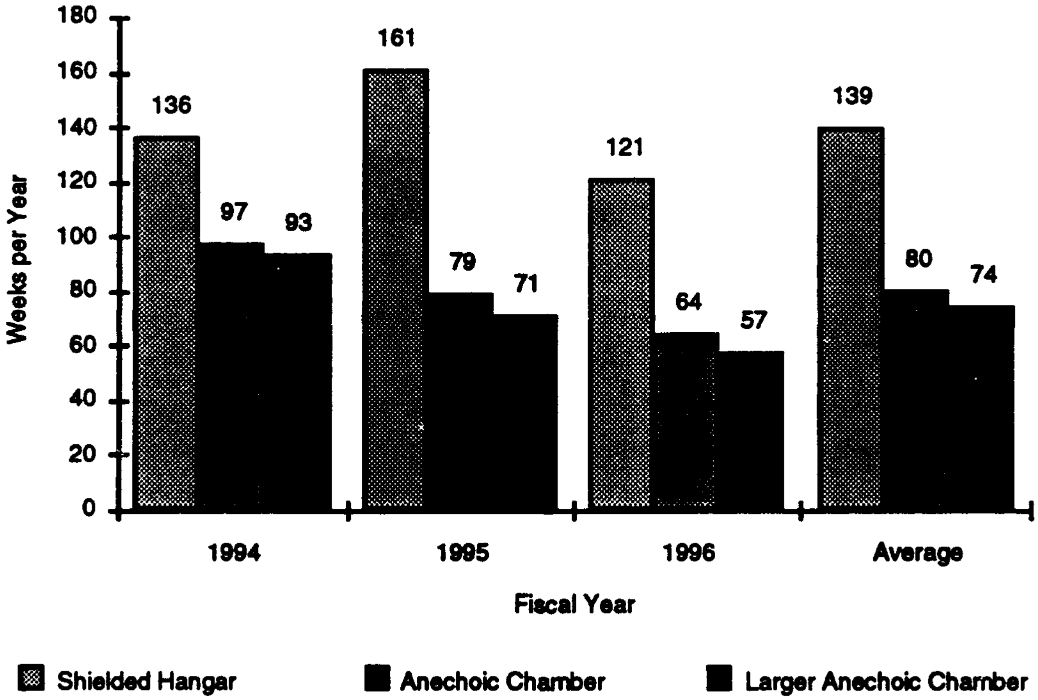


Figure 7. Navy Chamber Requirements

The shielded hangar at Patuxent NAS allows testing of more than one aircraft simultaneously, and a review of historical data since calendar year 1987 shows that an average of three to four different aircraft are tested each week there. Based on that data and those for the AATF, Navy usage can be expected to average more than one shift per workday for all three categories of chambers. Because personnel at Patuxent tell us that a

second shift (or even 2.5) is feasible for their anechoic chamber now, we assume that there is unused capacity at ACETEF now and in the foreseeable future.

Table 4 shows specific systems test requirements for chambers utilizing ACETEF, as provided by the Navy. The rows reflect the aircraft platforms and, in some cases, specific EC/avionics systems under test. The columns show requirements by fiscal year broken out by expected use of the shielded hangar (SH) or the SAC, both of which are on-hand, or a projected LAC. (The last is not as large as the BAF at the AFFTC, so it is sometimes called the intermediate anechoic chamber.) The Navy input was in workdays. IDA converted this to workweeks (5 workdays per workweek) to be consistent with the Air Force submission discussed in the next section.

Items in Table 4 under "GTRI" are from Georgia Tech Requirements Inventory [4] and were included in the requirements used to project Navy demand in Project Reliance deliberations.

Items under "NATC Probable" were developed by the Naval Air Test Center (NATC), now the Naval Air Warfare Center, Aircraft Division (NAWC-AD). This computation was based on the System Engineering and Test Directorate's assessment of anticipated usage, and was approved and/or modified by the program managers (PMs). As indicated in the table, some of the systems were changed by the PMs and some have since been canceled by the Navy. We retained their stated needs as "place holders" for future pre-planned product improvement (P^3I) of systems they were meant to replace, or of other replacement systems that will perform similar functions. At the bottom of the table, "Shifts" reduce the average weeks required in the small and large anechoic chambers to the number of equivalent work shifts required, assuming 48 weeks per year.

As already stated the Navy requirements do not include specific Army, Coast Guard, or Air Force systems which also use ACETEF. During FY 1989 through FY 1991 these requirements represented only about 6% of the NAWC-AD chamber workload. Navy requirements for the shielded hangar are included in the table, but do not enter into the analysis of requirements for anechoic chambers presented in later sections, because the shielded hangar is not a substitute for an anechoic chamber.

D. AIR FORCE REQUIREMENTS FOR ISTFS

The Air Force Electronic Combat Office (AFECO) at Wright-Patterson AFB was the focal point for Air Force requirements for use of installed systems test facilities

Table 4. Navy Estimate of Chamber Requirements (Weeks Per Year)

Navy Input	1994			1995			1996			Yearly Average			
	SH	SAC	LAC	SH	SAC	LAC	SH	SAC	LAC	SH	SAC	LAC	Total
GTRI													
ASEMICAP	6	6		4	4	4	4	4	4	4.7	4.7	2.7	12.0
EP-3 ARIES			8			4			8			4.0	4.0
E-6A HPTS				8						2.7			2.7
F-14 ASPJ		9			9			9			9.0		9.0
F-18 ASPJ		9			9			9			9.0		9.0
F-18 E3	8	8					8	8			2.7	2.7	5.3
Lightning	20			20			20			20.0			20.0
Mark XV IFF[a]	9	13	18	26	18	9				11.7	10.3	9.0	31.0
NATO/ATF E/O[a]				5						1.7			1.7
P-3				4						1.3			1.3
P-Static	24			24			24			24.0			24.0
Seek Spartan				1		11				0.3		3.7	4.0
V-22 E3	7			7			7			7.0			7.0
V-22 EW			13			13			13			13.0	13.0
Subtotal GTRI	74	45	39	99	40	41	55	22	17	76.0	35.7	32.3	144.0
NATC Probable													
A-12[a]	6	8	4	6	8	4	6	8	2	6.0	8.0	3.3	17.3
UAV		4	4		4	4		4	4		4.0	4.0	8.0
Attack Helicopter	2	2			3			8	3	5.7	2.3		3.7
ASW Helicopter	6	3		3	4		6	3		3	3.3		9.0
A-6[b]	4	5	3	8	3		2	2		4.7	3.3	1.0	9.0
H-53	3		2	2		1	2		1	2.3	1.3	1	3.7
E-2C	2		4	2		2	2		2	2.0		2.7	4.7
E-6A	2		4	2		2	1		1	1.7		2.3	4.0
EA-6B[b]	4	7	4	2		2	4	4	2	3.3	3.7	2.7	9.7
ERA-3B F/O[b]			3				4		4	3.0		5.0	8.0
P-7[a]	3		7	2		4	5		0	4.0		0	4.0
S-3[b]	4		0	3		0	4	4	4	5.0	5.0	2.7	12.7
F-14[b]	7	7	4	4	4		4	4	4		4.0	1.3	9.3
F-18		4		8	4		4		2	4.0		3.3	7.3
P-3	4		6	4		2					0.3		0.3
T-45	1							4		4	1.3	1.3	2.7
Other Government	8	6	6	8	5	5	8	6	6	8.0	5.7	5.7	19.3
FMS	4	3	2	4	2	2	4	3	2	4.0	2.7	2.0	8.7
FM Support	2		4	4	2	2	2	2	2	2.7	1.3	2.7	6.7
Subtotal NATC	62	52	54	62	39	30	66	42	40	63.3	44.3	41.3	149.0
Total	136	97	93	161	79	71	121	64	57	139.3	80.0	73.7	293.0
											Shifts = 1.7	1.5	3.2

[a] Canceled. Other P^3I follow-on systems expected to generate similar requirements.
[b] NATC projection modified by program managers.

(ISTF) for the Project Reliance deliberations. (Project Reliance is an ongoing initiative within the T&E community to assign Service and Defense Agency leads to functional areas of testing; these leads have a duty to minimize test facility duplication through a number of procedures such as needs validation and recommending centers of excellence to receive available funding for improvements.) The AF requirements are shown in Table 5 and total 190 weeks per year.

Table 5. Air Force Estimate of ISTF Requirements (Weeks Per Year, 18-Year Average)

Programs	Reliance Estimate	Current Estimate
B-1[a]	18	3
B-2[a]	0	2
C-17[a]	2	1
CV-22	0	12
C-130[a]	2	1
AC-130U[a]	0	6
EC-130[a]	18	20
MC-130CT[a]	16	12
C-141[a]	2	1
E-3[a]	4	5
JSTARS[a]	6	5
F-15	16	11
F-16	16	10
F-22[a]	27	10
EF-111	18	19
F-111	14	9
B-52[a]	9	0
TR-1/U-2	8	0
RC-135[a]	14	0
Total AF	190	127[b]

[a] Requires a large anechoic chamber.

[b] With 20% scheduling factor, this total becomes 152 weeks per year.

To answer the current tasking, AFECO convened an ISTF Requirements Conference of program offices, operational test organizations and AF major air commands (the users) to review the Reliance projections for relevancy to the FY 1995-2005 time. The negotiated final result, the average of requirements for ISTF over the 18-year period, is as shown in the last column of Table 5. The total need fell 33% from 190 to 127 weeks per year. However, AFECO believes that a 20% longer schedule is needed to ensure that the 127 weeks per year in the chamber would actually be met. The Navy point of contact agreed that this was a good planning factor. This 20% raises the AF requirement to 152 weeks per year. (This 20% was added to both Navy and Air Force requirements. IDA

performed sensitivity analyses both with and without the 20% factor, for Navy as well as Air Force requirements.)

A total of 51 weeks (40%) of the 127 weeks per year AF annual requirement are for systems too large to fit into the AATF at NAWC-AD. In order to be adequately tested, these platforms will require a facility such as the existing Benefield Anechoic Facility at Edwards or a new large anechoic chamber at NAWC. An as yet unmet requirement expressed by several Navy and AF tactical aircraft programs is that of testing electromagnetic compatibility among multiple aircraft in the same chamber. This also can be done only in a chamber larger than the AATF.

The Air Force requirements for installed systems test facilities is shown with Navy actuals and requirements in Figure 8. The breakout of AF small and large chamber requirements was done by IDA based only on the size of aircraft.

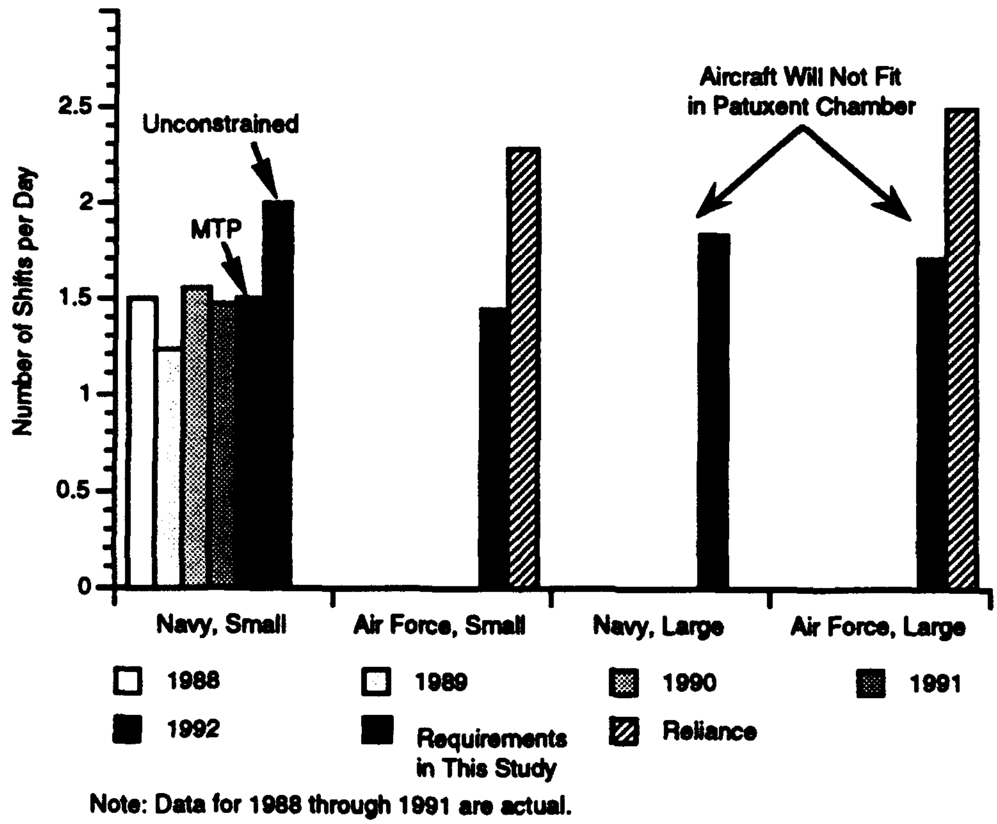


Figure 8. Navy and Air Force ISTF Requirements (Comparison of Weeks per Year)

The scale is in average number of shifts per day over the course of a year. One shift-year equals 8 hours per day, 48 weeks per year of anechoic chamber usage on average. The remaining four weeks per year is downtime for maintenance, upgrades, holidays, etc. Navy actuals are of utilization of the small anechoic chamber at ACETEF ("Navy, Small") for FY 1988 through FY 1991. We see in the figure that Navy usage has grown to one shift equivalent through FY 1991, with the planned MTP (Manage to Program) equal to 1.5 shifts in FY 1992. Service forecasts of ISTF needs (Requirements in Study) in almost all cases have been validated by the applicable program management offices. Validated (and unconstrained) Navy projections are for two shift-year equivalents over FY 1994 through FY 1996. The other series in the figure show forecasts of AF small chamber and Navy and AF large chamber requirements. AF forecasts for both tactical and large aircraft are lower in total than their Navy counterparts. In summary, the Service forecasts of ISTF requirements for electronic combat/avionics ground testing seem in consonance with past Navy experience.

If one compares the AF requirements with those of the Navy for somewhat similar systems, it would appear that either those of the Air Force are understated or the Navy's are overstated. We believe that those of the Air Force are low, perhaps because some in the AF do not have a full appreciation of such capability as has been developed by the Navy at ACETEF. Aircraft systems with no stated requirements include the C-5, the C-27, and the F-117.

E. INSTITUTE FOR DEFENSE ANALYSES ESTIMATES

1. Assumptions

We assumed for the purpose of our analyses that the Navy requirements data reflect annual requirements not only through FY 1996 but also for the foreseeable future. We also assumed that reductions in test requirements arising from the ongoing force drawdown and diminished procurement will be offset by increases from retrofits, greater avionics complexity, and expanded testing resulting from the new acquisition policy of longer development, thorough evaluation, and deferred production. (This also could mean the testing of major upgrades to existing systems at the same time as new (potentially replacement) systems are being tested in engineering development.)

Air Force and Navy experience and future requirements are compared in Table 6. The Air Force estimates are comparable to the Navy experience, but less than the Navy estimates. The Air Force's current estimate for tactical aircraft is approximately three-

fourths of the Navy's FY 1994-96 SAC requirements. The Air Force's current estimate for large aircraft is about the same as the Navy's LAC requirements for FY 1994-96. The F-15 and F-16 estimates approximate the F-14 and F-18 experience and are less than the estimated requirements for the F-14 and F-18. An average of two to three weeks per year in an anechoic chamber for the B-2 and B-1B and none for the F-117 is questionable when compared with other systems. On the whole, the Air Force requirements appear to be conservative when compared to Navy experience.

Table 6. Weeks per Year of Test Requirements: Air Force Estimate and Navy Experience

Air Force Programs	Reliance Estimate	Current Estimate	Navy Programs	Requirements Met	Requirements Unmet	FY 1994-96 Estimate
Tactical	91	59	SAC	44	134	80
F-15	16	11	F-14	9	16	17
F-16	16	10	F-18	13	39	17
F-22	27	10	A-12			11
F-111	14	9	A-6	2	5	4
F-117			V-22		5	13
EF-111	18	19	Misc.	9	28	10
Helo			Helo	5	22	6
Large	99	68	LAC			74
B-1B	18	3	P-7			5
B-2		2				
B-52	9					
JSTARS	6	5	EP-3 ARIES			4
E-3	4	5	E-2	1	2	3
Misc.[a]	62	53	Misc.[a]			62

[a] Specific systems are identified in Tables 4 and 5.

We had to assume that the three years of stated Navy requirements are representative of those throughout the period of interest, and that the 18-year annual average of AF tests requiring an ISTF could be applied uniformly in all years. In fact, there would be peaks and valleys of demand, but these could normally be smoothed through priorities, and we so assumed. The one system that we treated differently was the F-22. The bulk of its testing is expected to be required in FY 1995-1999. Because of the Systems Program Office (SPO) estimates of sizable deployment costs, we had to treat it as a special case, with different values for needs met before FY 2000 and after.

2. Requirements for Laboratories/Clusters Supporting the Anechoic Chamber

As described more fully in Section IV, an ACETEF or ECIT capability is much more than a mere anechoic chamber. These capabilities represent a group of test functions

that use the chamber as a tool. (The Navy uses the term "laboratory" and the AF the term "cluster" to identify a function that supports testing in its anechoic chamber. For consistency, we refer to them as "functions.") The data provided by the Navy and the AF did not identify the functions that would be used during the weeks the programs were in the chamber. (This would be a large task as it would require access to often classified, sometimes compartmented material detailed in specific avionics test plans, if they exist.) Members of the Operational Evaluation Division of IDA looked at the list of AF systems and categorized what EC test functions they might require. This was based on an informed judgment of the platform's intended mission and its anticipated EC/: vionics suite.

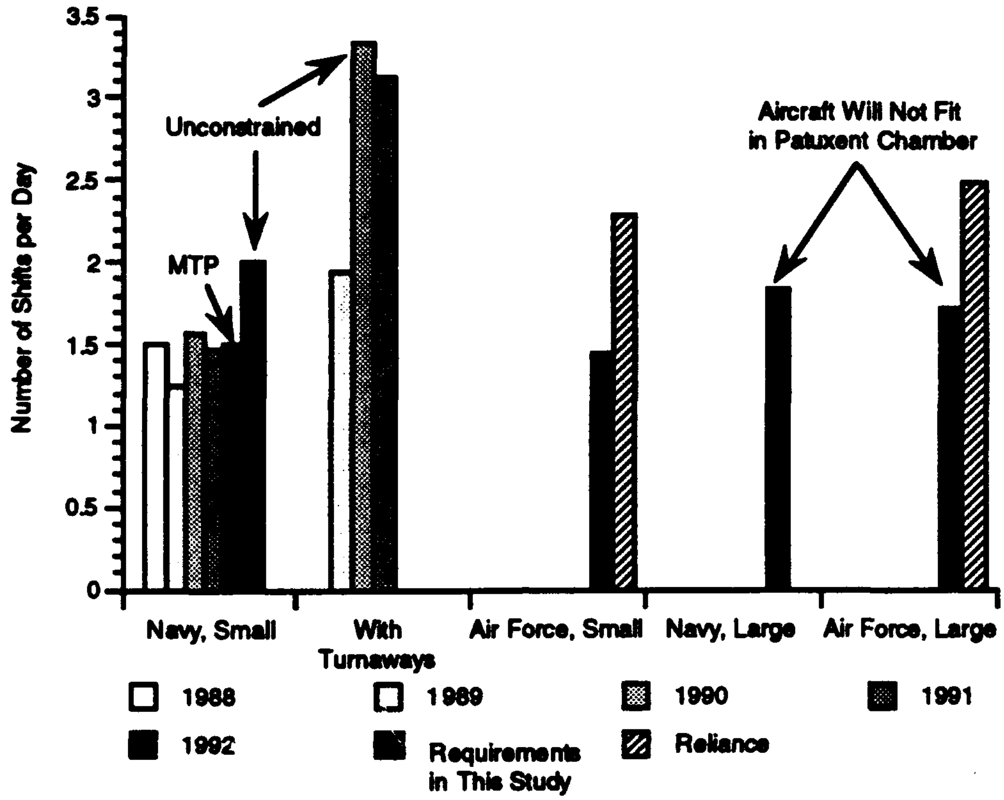
3. Total Electronic Combat Test Requirements for ISTFs

Figure 9 compares historic requirements for use of the AATF at Patuxent NAS with those forecast by the Navy and Air Force. A review of macro data on use of the AATF in calendar years 1989 through 1991 shows weeks in the chamber of 40, 45, and 48 respectively, or increasing to 1.0 shifts on a 48:1 basis. During those years, the same data indicate that NATC turned away an average of another 134 weeks (three shifts) annually. (This number may be overstated because there may be some multiple counting of turnaways requesting the same testing more than once, and of turnaways whose requests were later filled.)

The AATF is expecting to use 1.5 shifts in FY 1992, which equates to 72 weeks in the chamber. This is labeled MTP (Manage to Program) meaning that it is based on being able to serve that number within expected funding, etc. The AATF FY 1994-1996 forecast of small chamber requirements, which we assumed would hold constant for 20 years, is for 80 weeks annually (96 weeks or 2.0 shifts with the 20% schedule flex). Although 50% higher than the current level, the requirement seems modest compared to the sum of historical usage plus turnaways.

We do not have any AF historical data but the AF forecasts look roughly right when compared to those of the Navy. No historical data are shown for the Navy LAC requirements either, because, except for some B-1B testing and perhaps a small amount of other EC testing in the BAF, a significant ISTF capability incorporating a LAC does not exist. The Project Reliance levels are shown to depict the AF "scrub" of requirements to get to the levels used in this study. Navy LAC requirements include tactical-sized aircraft where such was indicated (see Table 4). All of the F-22 requirement but no other tactical-size AF aircraft are shown in the "AF, Large" requirements because we had no break-out of

the F-22 needs and no indication that other AF tactical platforms had a large anechoic chamber requirement, although some probably do.



Note: Data for 1988 through 1991 are actual.

Figure 9. Electronic Combat ISTF Requirements

VI. COST AND EFFECTIVENESS ANALYSIS

Previous sections of this report covered existing ISTF capabilities and possible enhancements to those facilities (Section IV) and the projected Service requirements for ISTF testing (Section V). This section focuses on the costs and effectiveness of the ISTF alternative enhancements in satisfying the requirements.

A. COSTS

In this subsection, we present the costs associated with the alternatives previously identified. Table 7 summarizes the cost estimate for the "base case,"[13] and includes investment, 20-year operating, and deployment costs.

Table 7. Cost Summary (Millions of Constant FY 1992 Dollars)

	Alternative Number			
Cost Element	1	2	3	4
Baseline ACETEF	$60	$60	$60	$60
Investment	$0	$68	$168	$236
20-Year Operating	$0	$54	$229	$283
Deployment Cost	$202	$272	$28	$8
Total	$262	$454	$486	$589
Discounted at 10% per year	$167	$249	$264	$328

The base case methodology is described in succeeding paragraphs, while excursions to the base case are documented in Appendix E. Additional supporting data can be found as follows:

- Appendix A contains data on investment costs.
- Appendix B shows the methodology for converting to constant FY 1992 dollars.
- Appendix C contains data on operating costs.
- Appendix D contains data on deployment costs.

[13] The base case uses the IDA estimate of cost of deployment, described in Section VI.A.3.

1. Investment Costs

We previously described approved and programmed enhancements to the ACETEF. All four alternatives we considered in this study assume that these enhancements, described in Table 7 as the Baseline ACETEF, will be completed, at a cost of $60.5 million in constant FY 1992 dollars. Tables 8 and 9 summarize overall investment costs associated with all four alternatives. Table 8 shows investment costs in constant FY 1992 dollars for all ACETEF capabilities. While future costs are the only relevant costs for investment decisions, we included the historical (sunk) costs of $271.5 million as well as the future costs of $60.5 million to provide a complete baseline from which to estimate future ECIT capabilities and related costs by analogy. Only future costs for ACETEF are included in the four alternatives.

Table 8. ACETEF Investment Costs (Millions of Constant FY1992 Dollars)

	Historical Costs (Through FY 92)	Future Costs	Total Costs
Baseline ACETEF			
Building Construction (MILCON)			
Small Anechoic Chamber (SAC)	$18.3		$18.3
Shielded Hangar (SH)	86.3		86.3
Aircrew Systems Evaluation Facility (ASEF)	13.3		13.3
Lab improvements (RDT&E)			
EWISTL	17.3	$10.6	28.0
Manned Flight Simulator (MFS)	57.7	9.4	67.1
Electromagnetic Environmental Effects Test Lab	30.3	3.5	33.7
Shielded Hangar (SH)			
Closed-Loop Facility	25.6	3.7	29.3
Aircrew Systems Evaluation Facility (ASEF)	3.1	2.6	5.7
Operations and Control Center (OCC)	4.2	8.2	12.4
Offensive Sensors Lab (OSL)	5.8	15.0	20.8
CNI Lab	9.6	7.6	17.2
Total	$271.5	$60.5	$332.0
Large Anechoic Chamber (LAC) at ACETEF			
Building Construction (MILCON)		$68.0	

Alternative 1 has no additional investment cost, because this alternative involves increased throughput, achieved by increasing to 2.5 shifts per day. No additional facilities are required.

Alternative 2 builds a large anechoic chamber at ACETEF, and costs $68.0 million in constant FY 1992 dollars, also shown in Table 8. The cost estimate was provided by the Navy, who had proposed to build the chamber several years ago, and studied the cost in

some detail. We accepted the value as reasonable. By comparison, the BAF cost about $50 million when it was built as part of the B-1B contract in 1988.

Table 9. ECIT Investment Costs (Constant FY1992 Dollars in Millions)

	Equivalent ACETEF Capability	Future Costs	
ECIT			
Generic (Facility Infrastructure)			
Anechoic chamber cluster	EWISTL	28.0	
Management, control	OCC	10.5	
Other	Multiple	14.8	
Program management	Multiple	18.6	
Total generic program			71.9
Full Function Category 2 ISTF			
Building construction (MILCON)			
Aircrew Systems Evaluation Facility		13.3	
Lab construction (RDT&E)	ASL		
MFS cluster		72.8	
CNI cluster	MFS+ASEF	17.2	
Electro-optical/Infrared cluster	CNI	20.8	
RF/Electronic warfare cluster	OSL		
Management and control	Multiple	1.9	
Adjustments	OCC		
Double counting of equipment interfaces		-14.8	
Anticipated price reduction[a]		-14.7	
Total long-term program			96.5
Total generic plus long-term programs			168.4

[a] 15% of historical cost of EWISTL, MFS, ASL, OCC, OSL, and CNI.

Alternative 3 develops the ECIT into a full function Category 2 ISTF by adding considerable simulation, stimulation, and command and control capability. We broke the cost into two parts, the generic infrastructure capability, which theoretically represents what the Air Force intended to provide with the $60 million program that was to start in the FY 1992 President's Budget and the additional enhancements needed to satisfy minimum F-22 requirements. (See Section IV.C.2. for a discussion of these enhancements.) Table 9 shows all future investment costs in FY 1992 constant dollars for the planned ECIT capabilities. We did not include historical costs because they were not relevant to the analysis. As shown in Table 9, the total cost is $168.4 million. The generic upgrade program is $71.9 million. We estimated that an additional $96.5 million would be required to meet F-22 needs and would perhaps be paid from program funds. Both figures were estimated by analogy to the ACETEF capabilities. While this is just one of a full spectrum of possible ECIT configurations and costs, we selected the configuration above because it

gives an equivalent capability to that of ACETEF. The $60 million program is not sufficient in itself.

2. Operating Costs

For each alternative, we computed operating costs that were additive to current operating costs for ACETEF and ECIT; that is, we assumed that current costs will continue and do not vary among the four alternatives. We also assumed that, apart from deployment costs, which are treated in the next subsection, the cost of performing any given test program is the same at ECIT or ACETEF. Consequently, only those operating costs associated with increased facilities (Alternatives 2, 3, and 4) have a bearing on the analysis. We calculated the 20-year additive operating cost of Alternative 2 at $54.1 million, Alternative 3 at $229.1 million, and Alternative 4 at $283.2 million. These additive costs are due to increases in test workload supported and the operation of an additional chamber in Alternatives 2 and 4. The methodology we used is described in detail in Appendix C. The ECIT operating cost appears to be unusually high, but that is because the supporting functions are low, whereas ACETEF starts from its present high capability. The operating cost of program-specific testing is not included. We assumed it would be approximately the same at either location.

3. Deployment Costs

The Air Force position is that ground testing an F-22 at Patuxent NAS would incur substantial costs over and above those for testing the same aircraft at Edwards. The reason is the F-22's new start situation and its integrated electronic combat/avionics systems. It also is tied to the Air Force's testing philosophy, which calls for collocation due to close coordination and correlation between flight and ground (chamber) testing (see Section III). At the same time that F-22 Combined Test Force (CTF) personnel and equipment would be deployed to Patuxent NAS, a full complement of the CTF technical personnel and equipment would have to be left at Edwards to work with the flight test program, which would remain at Edwards. An F-22 systems integration laboratory (SIL) with two avionics lines would be constructed at Patuxent NAS with 75 people to run it. Moreover, the Air Force states that results obtained in Maryland would have to be correlated with those at the IFAST in California, so there would be no savings in the ground test program at the latter location. Not only would the avionics test aircraft remaining at Edwards be unable to make up the flight tests now scheduled for the test article going to ACETEF, but 25% more additional flights would be required to correlate results obtained at the two locations.

The F-22 is the only program for which an estimate of deployment costs to ACETEF was provided. See Appendix F for the detail and rationale of this estimate. For all the other Air Force programs (and for Navy programs deployed to ECIT for some excursions in Alternative 4), we used AF standard average deployment costs for tactical and for large aircraft systems. AF systems such as the F-16 and the C-130 have deployed normally to ACETEF for short periods in the past, but none was an extensive new development such as the F-22.

The numbers in Table 10 show the deployment costs and number of weeks of testing for an Air Force average annual testing program if all aircraft were deployed for the average length of time stated in the requirements. We divided the deployment costs by the testing periods because the costs are dependent on time. Much of the deployment cost is personnel per diem, and personnel on temporary duty for testing projects exceeding six weeks in duration are allowed monthly visits home. The F-22 was treated as a special case since we had additional information from the program office.

Table 10. Testing Requirements and Deployment Costs

	ISTF Testing Weeks per Year		
	Service Data	Including 20% Scheduling Allowance	Cost per Year, if Deployed (Millions of FY 1992 Dollars)
Navy			
Tactical aircraft	80	96.0	
Large aircraft	74	88.4	
Air Force			
F-22			Special Case
First 5 years	21	25.2	
Thereafter	8	9.6	
Other tactical aircraft			
EF-111	19	22.8	1.3
F-15	11	13.2	0.8
F-16	10	12.0	0.7
F-111	9	10.8	0.6
Large aircraft			
AC-130U	6	7.2	0.5
B-1	3	3.6	0.4
C-17	1	1.2	0.3
C-130	1	1.2	0.3
C-141	1	1.2	0.3
E-3	5	6.0	0.4
EC-130	20	24.0	1.6
JSTARS	5	6.0	0.4
MC-130CT	12	14.4	1.0
CV-22	12	14.4	1.0
B-2	2	2.4	0.3

The values in Table 10 were used to calculate average deployment costs per week for tactical and large aircraft of $58,000 and $79,000, respectively. (Details of this derivation are in Appendix D.)

The F-22 Systems Program Office (SPO) estimated that it would cost $309 million more in constant FY 1992 dollars to deploy to ACETEF that portion of the F-22's EC/avionics ground test program involving an ISTF than to conduct that ground testing at Edwards, where flight testing and other ground testing will be conducted. This estimate included the cost to construct a systems integration laboratory (SIL) with two avionics bench-test lines at Patuxent River NAS adjacent to ACETEF and its chamber.

The AF rationale for this estimate was that the F-22 is a major new development that incorporates the most technologically advanced electronic combat/avionics systems ever undertaken by the DoD. As a result, the Air Force considered it essential that a SIL (or hardware-in-the-loop) facility be collocated with the ISTF if the ISTF is not collocated with the flight test program. The $309 million represents the total cost to the F-22 program associated with build-up and 26 months with an F-22 avionics test aircraft in an anechoic chamber at ACETEF. At the other end of the spectrum, similar deployment to ACETEF of previous operational aircraft for tests of limited duration and scope without a collocated SIL was estimated to cost only $15 million.

IDA developed a "middle ground" deployment estimate of $148 million, which included building a single-line SIL at ACETEF with fewer people, fewer spares, less equipment, and less duplicative flight testing than included in the F-22 estimate. We believed this estimate to be a reasonable balance between risk and affordability. Figure 10 shows the impact on cost of using the various deployment estimates.

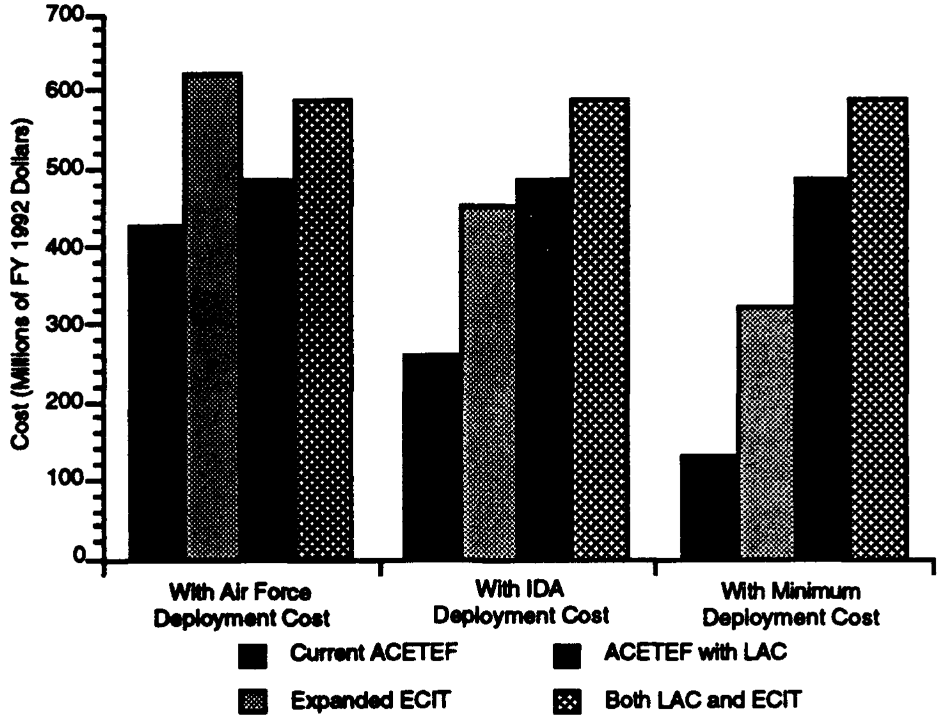
4. Total Systems Costs

Table 11 pulls together the investment, operating, and deployment costs derived in the previous tables to construct the 20-year systems cost of each of the four testing alternatives. The 20-year costs are the sum of investment plus 20 years of additive operating and deployment costs. We chose a 20-year cost horizon because of the long life of the resources we are analyzing (test chambers and functions).

As already discussed, the operating and deployment costs depend partly on the number of shifts that the chambers are operated, and the extent of the Air Force testing program that is deployed to ACETEF.

Cost estimates for the alternatives using the three deployment estimates are summarized in Table 11. The medium (IDA) estimate is the base case, with the high (SPO)

estimate and low (minimum deployment) shown for comparison. A discussion of their relative costs follows the effectiveness analysis described in the next subsection.



Note: Costs include investment and 20-year operations costs.

Figure 10. Undiscounted Costs of Alternatives

Table 11. Costs and Effectiveness of Testing Alternatives

	Testing Shortfall (Shift-Years)		20-Year Systems Cost (Millions of FY 1992 Dollars)					
			Total Cost			Discounted		
Alternative	First 5 yrs	Thereafter	Low	Medium[a]	High	Low	Medium[a]	High
1 Expanded ACETEF	4.79	4.47	132	262	428	75	167	281
2 ACETEF + LAC	3.29	2.97	324	454	620	165	249	352
3 ACETEF + ECIT	2.29	1.97	486	486	486	264	264	264
4 Alt. 2 + Alt. 3	0.79	0.47	589	589	589	328	328	328

[a]Base case.

B. EFFECTIVENESS ANALYSIS

A measure of effectiveness of each testing alternative is the proportion of the testing program it can perform. For example, if the Navy and Air Force together have a testing requirement of 7 shift-years and the testing alternative can deliver four shift-years, there is a shortfall of at least 3 shift-years. The smaller the shortfall, the more effective the alternative.

In estimating the ability of only-ACETEF alternatives to handle both Navy and Air Force testing programs, we made the simplifying assumption that capacity would be divided between the Services. In alternatives that had ISTFs at both Patuxent and Edwards, each location would give first priority to the testing programs of its own Service. Thus, the ACETEF facility would give first priority to the Navy test program, and perform Air Force testing with whatever excess capacity was left over. Edwards would give first priority to Air Force programs. The assumption makes no judgment about the relative value of the respective programs. The effectiveness for each alternative is measured by the ability of the alternative to handle the *total* program, Navy and Air Force combined.

With one exception, we assumed that Air Force tactical aircraft require a small chamber and Air Force large aircraft require a large chamber. The exception is the F-22. Although a single F-22 would fit in a small chamber, the F-22 SPO states the requirement to group several aircraft together for chamber testing, in order to test interactions between aircraft. This would require a large chamber. In Alternative 1, in which there is no large chamber, we assumed that the F-22 would be tested as a single aircraft at ACETEF using the existing small chamber.

C. SUMMARY OF COST AND EFFECTIVENESS

In Figure 11 we attempt to show costs and capacity beyond that already spent and programmed for ACETEF. The scale and the stacked bar to the left of each series shows the cost of each alternative. The scale and the bar to the right of each series shows additional capacity purchased. Figure 12 shows the same information using dollars discounted at 10% per annum over the cost stream, the usual measure for economic analyses in DoD.

Tables 12 and 13 display the same data in tabular form. The more we spend, the more effectiveness we obtain, as measured by the percentage of the testing program that can be accomplished. Note that in each successive alternative the cost per unit of added capacity is lower. Using the medium (IDA) F-22 deployment costs and discounted dollars (Table 13), as we move from the first through the fourth alternative, the 20-year discounted costs about double (increase from $167 to $328 million), but the percentage of the Services' testing requirements we can perform (after the initial 5-year period) increases greatly, from 36% to 94%. Similar tables showing sensitivity analyses using both higher and lower F-22 deployment costs, and higher and lower Service requirements for testing, are in Appendix E.

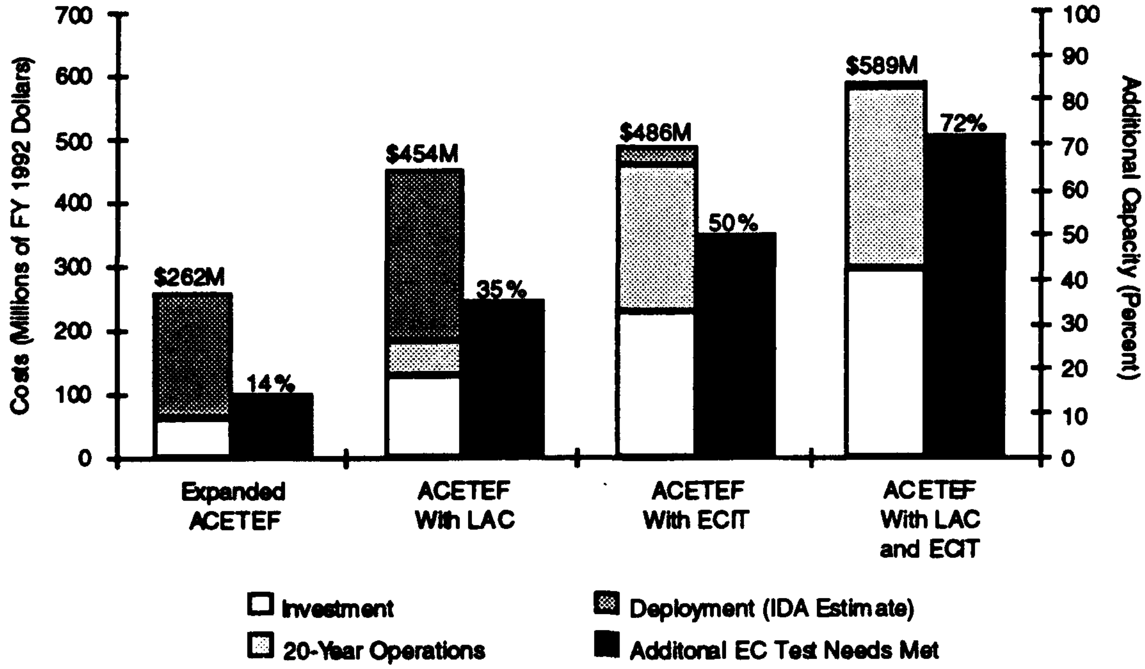


Figure 11. Costs Versus Needs Met (Constant FY 1992 Dollars)

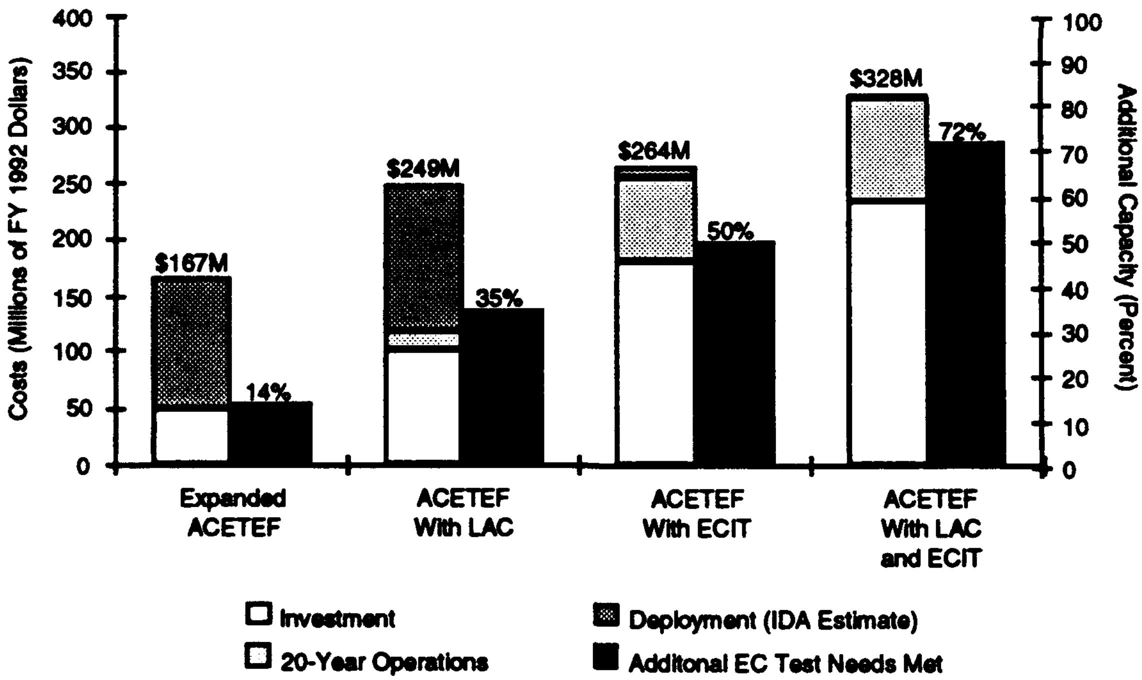


Figure 12. Costs Versus Needs Met (Discounted FY 1992 Dollars)

Table 12. Needs and Constrained Costs with IDA Deployment Estimate (Millions of Constant FY 1992 Dollars)

	Alternative/Description	Percent of Needs Met	Increase in Needs Met	Additive Costs[a]	Cost Per Percent of Added Needs Met
0	Baseline ACETEF	22%	0%	$60	NA
1	Provide 2.5 Shifts at ACETEF	36%	14%	$262	$18.7
2	Build LAC at Patuxent with 4 Shift Capacity	57%	35%	$454	$13.0
3	Build ECIT at Edwards (and Alt. 1 ACETEF)	72%	50%	$486	$9.7
4	Build LAC and ECIT (Alt. 2 + Alt.3)	94%	72%	$589	$8.2

[a] Uses IDA estimate with fiscally constrained F-22 deployment. Costs include future investments, 20-years of operations and deployments. Constant FY 1992 dollars are undiscounted.

Table 13. Needs and Constrained Costs with IDA Deployment Estimate (Millions of Discounted 1992 Dollars)

	Alternative/Description	Percent of Needs Met	Increase in Needs Met	Additive Costs[a]	Cost Per Percent of Added Needs Met
0	Baseline ACETEF	22%	0%	$50	NA
1	Provide 2.5 Shifts at ACETEF	36%	14%	$167	$11.9
2	Build LAC at Patuxent with 4 Shift Capacity	57%	35%	$249	$7.1
3	Build ECIT at Edwards (and Alt. 1 ACETEF)	72%	50%	$264	$5.3
4	Build LAC and ECIT (Alt. 2 + Alt.3)	94%	72%	$328	$4.6

[a] Uses IDA estimate with fiscally constrained F-22 deployment. Costs include future investments, 20-years of operations and deployments. FY 1992 dollars are discounted at 10% per annum.

Note that the second and third options are relatively close together, and relatively separated from Alternatives 1 and 4, in terms of both cost and effectiveness. The fact that Alternatives 2 and 3 are similar in cost is not intuitive; it arises from the fact that whereas building a new chamber at Patuxent costs less than improving the BAF at Edwards AFB, there would be considerable cost in deploying a new-development Air Force aircraft to Patuxent for flight test.

A measure of merit in both Table 12 and Table 13 is the "cost per percent of added needs met. In discounted dollars (Table 13), we see the cost of additional needs met decreasing from Alternatives 1 to 2 to 3 to 4 because each adds capacity at a greater rate than it increases cost. In both constant and discounted dollars, the most cost-effective alternative under this measure of merit is Alternative 4. Since one can get to Alternative 4 either via Alternative 2 or Alternative 3, it would appear that the prudent choice might be to select Alternative 3 (ECIT) as the first step, as it yields a substantially greater payoff for

relatively small additional cost. There are other, unquantifiable considerations (described in Section VII) that also affect the decision.

VII. OTHER CONSIDERATIONS

This section details a number of considerations that, while unquantifiable, we felt were worthy of mention here. Most support the acquisition of additional installed systems test capability at Edwards AFB, although some reinforce the concentration of expertise at Patuxent NAS.

A. SERVICE-UNIQUE REQUIREMENTS

The Naval Air Warfare Center (NAWC) has as its primary mission the support of the Navy's fleet air arm. If the principal job of the ACETEF activity over an extended period of time were to support higher-priority Air Force aircraft programs, would fleet support suffer? For example, the F-22 requirement of 26 months in the chamber over a four- or five-year period would monopolize that facility and potentially all of its labs. More importantly, the talents of the best ACETEF personnel would be solving F-22 problems. Who works on Navy systems and problems during this period? On the other hand, if the F-22 were developed using ACETEF exclusively, who supports block upgrades and needs that arise later during AF operations? The expertise and experience to do so will not be readily available within the Air Force. Operational systems are currently the only ones in test at ACETEF.

B. CONSIDERATIONS AFFECTING FUTURE ISTF WORKLOAD

1. Impact of Declining Defense Budgets

With the "drawdown" in defense spending, is it prudent for the test community to undertake investments that significantly increase its capacity? If DoD can test smarter with new facilities, where and what are the resulting savings? Can we reduce test flying hours or are the savings only in risk reduction? These policy questions are outside the scope of this study but need to be considered.

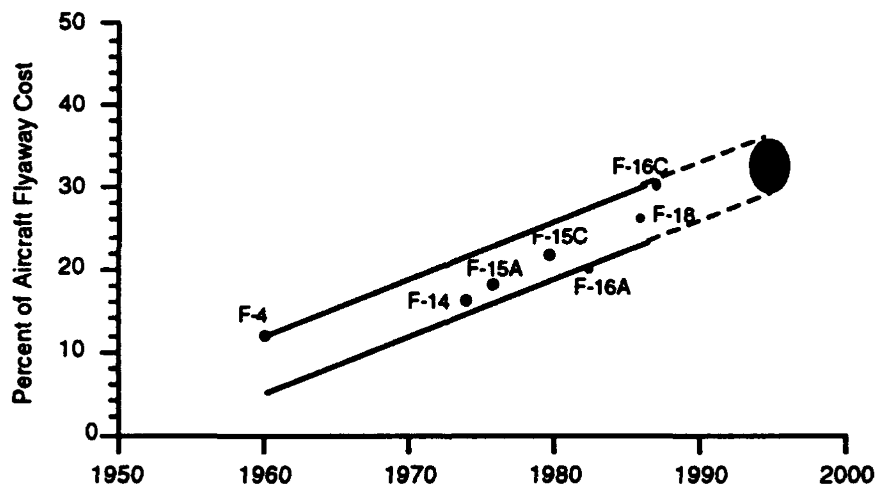
2. New Defense Acquisition Strategy

A fact sheet on Deputy Secretary of Defense Atwood's new approach to Defense acquisition states that "particular efforts must be made to eliminate cost growth, schedule

delays or trial-and-error during production. The Department will be able to proceed to production of a weapon system only after thoroughly demonstrating the effectiveness of the technologies involved.... Accordingly the Department will emphasize technology demonstration and prototype evaluation programs." It further states that advanced technology is to be incorporated in new or existing weapon systems only if "the technology and associated systems are thoroughly tested and proven" [2]. Such a policy clearly requires a strong electronic combat/avionics test capability.

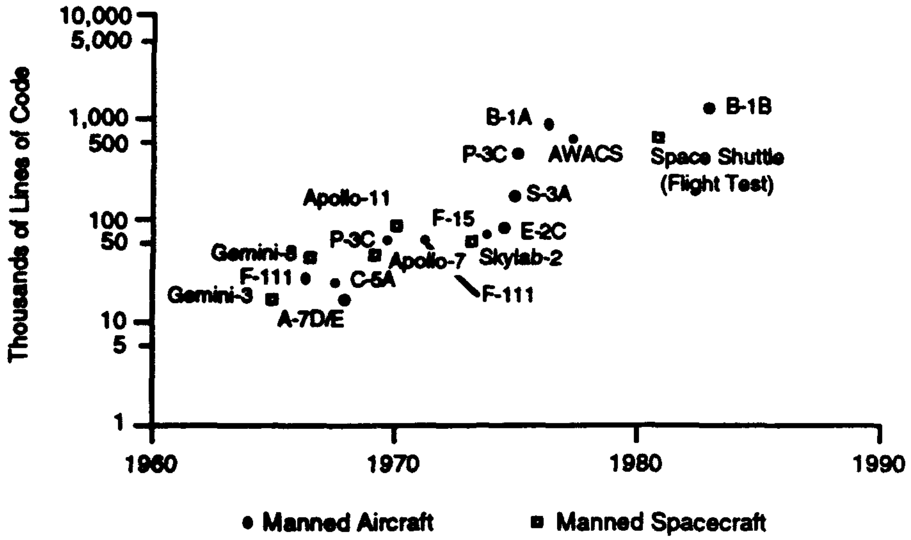
3. Increased Demand for Ground Testing

Experts within both the program management and test communities believe that future demand for the ground testing of electronic combat/avionics will increase due to the increasing complexity of avionics and the need for a significant amount of ground testing from early development through operations. Figures 13 and 14 show the growth of avionics (1) as a percentage of aircraft flyaway cost and (2) in terms of lines of software code in air and space systems. As electronic combat and other avionics packages become more integrated and complex, either in new aircraft or in retrofits, better ground facilities are needed. For example, the multi-spectral threat cannot be tested on open ranges.



Source: Longbrake, Ronald B. "Avionics Acquisition, Trends and Future Approaches." NATO Advisory Group for Aerospace Research and Development (AGARD), Conference Proceedings No. 424: Flight Vehicle Development Time and Cost Reduction, pp. 11-1 to 11-11.

Figure 13. Avionics Growth as a Percentage of Aircraft Flyaway Cost



Source: James W. Canan. "The Software Crisis," *Air Force Magazine*. May 1986, pp. 46-52.

Figure 14. Avionics Growth in Terms of Lines of Software Code

4. Lead Times Necessary for Facilities to Test New Advanced Technologies

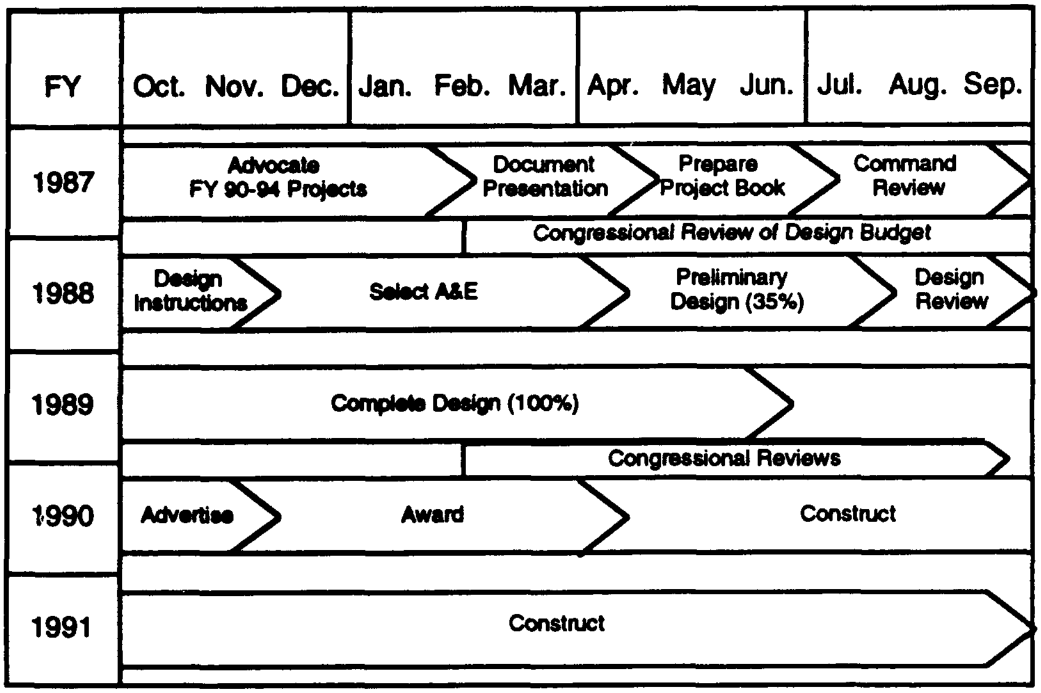
Figure 15 shows typical lead times in acquiring facilities through the military construction process. Planning and administrative times average about 3.5 years with 1.5 years more in actual construction to acquire the required test capability. This schedule dictates that facility construction needs to be started long before the facility is needed.

5. Availability of Experienced Work Force

Because the ACETEF work force is already experienced, building an expanded capability at Patuxent River would be easier and quicker than starting an essentially capability at Edwards.

6. Potential to Meet Workload Surges

Even if one ISTF had the capacity to satisfy critical DoD requirements, there would be value in having two to meet workload surges or the catastrophic loss of one. This is a significant concern considering the cost to fix problems later due to the lack of a T&E capability or the cost to delay the schedule of a major program.



Source: Derived from historical data by Arnold Engineering Development Center, 1988.

Figure 15. Construction Lead Times

C. PROJECT RELIANCE: THE NEED TO MAKE IT WORK

"Project Reliance" is an initiative of the Joint Commanders Group, Test and Evaluation, to promote efficient multi-Service use of T&E investment and facilities and to eliminate unwarranted duplication of T&E facilities. Over the course of a year, the Electronic Warfare (EW) T&E Reliance Study Group assessed the spectrum of test support resources: digital models and computer simulation, integration laboratories, hardware-in-the-loop test facilities, open air ranges, and measurement facilities as well as the installed systems test facilities (including anechoic chambers) that are the focus of this report. The Study Group recommended in part [3]:

- The Navy should be designated as lead Service for ISTFs.
- An ISTF EW T&E Resource Master Plan should be developed by the Navy assisted by the Army and the Air Force.
- The ISTF EW T&E Resource Master Plan should consider (1) developing ACETEF into the highest capability (Category I) ISTF, (2) authorizing planning for a larger anechoic facility at NAWC-AD, but deferring construction until "future workload requirements are demonstrated and the DoD budget

picture stabilizes," (3) developing a large, enhanced-capability (Category II) ISTF at Edwards with emphasis on support for new-generation systems.

These recommendations endorse the need to upgrade the electronic combat/avionics ground test capabilities both at Patuxent and at Edwards.

With the Project Reliance Memorandum of Understanding signed, the framework is in place to begin a coordinated multi-Service approach to proceed with improvements while minimizing potential duplication. It is our opinion that the Reliance process should be given the opportunity to work.

D. TEST FACILITY DUPLICATION VERSUS OPTIMIZATION FOR WEAPON SYSTEM ACQUISITION

1. Relative Costs of Test Facilities and Weapon Systems

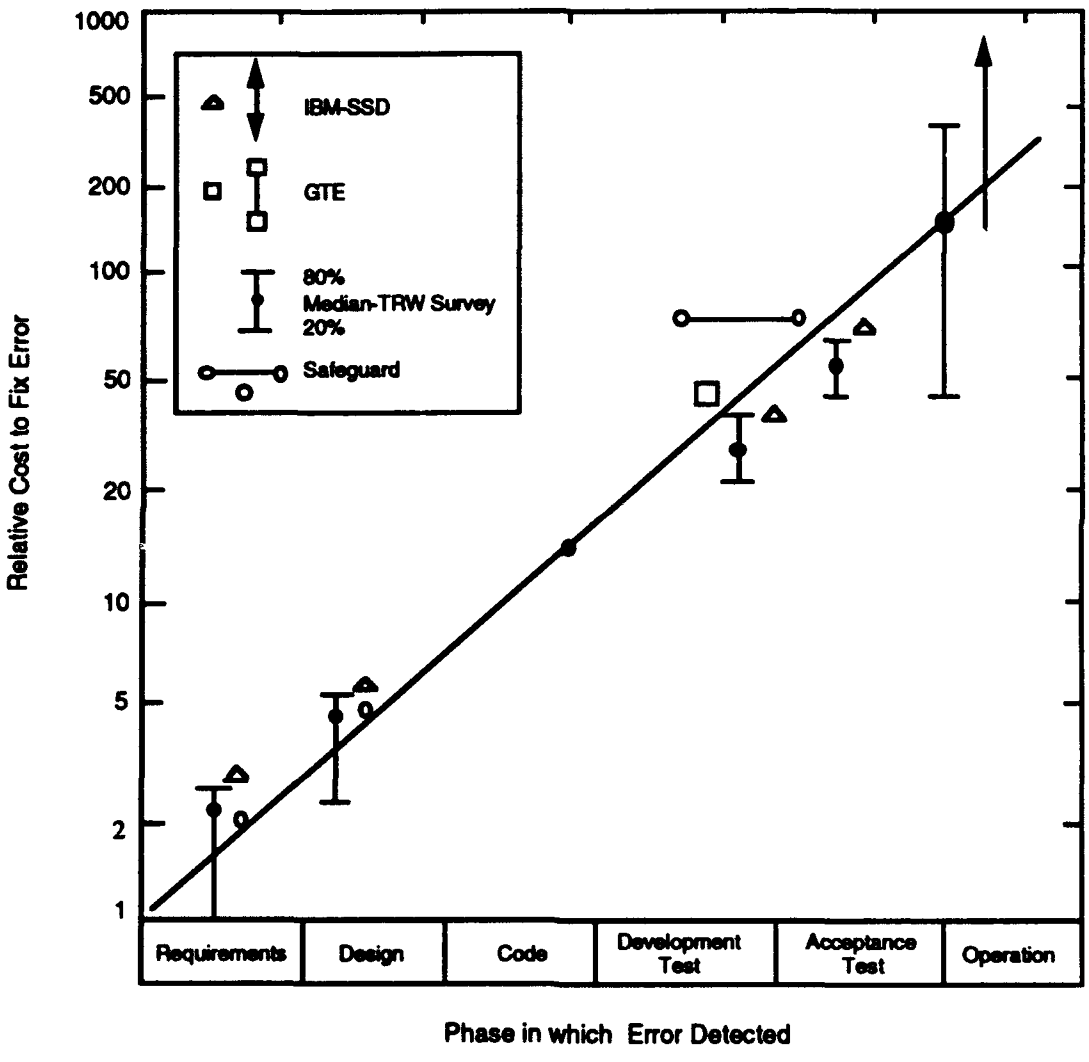
In order to produce the strongest defense for a given level of resources, the entire acquisition process must be considered. This may require some duplication of test assets in order to minimize the cost of weapon system acquisition. A theoretical example is procuring two $10 million test instrumentation packages in order to prevent production delays costing $100 million.

The cost of the new capabilities we are talking about in this paper, while substantial, are not large compared to the cost of the systems they are designed to support. For example, the FY 1993 unit cost of the B-2A is $1 billion, the C-17, $335 million; even "end of the production line" aircraft such as the F-16 and C-130 have FY 1993 unit costs over $30 million [56]. A relatively small test investment may leverage huge acquisition investments and significantly reduce overall acquisition costs.

2. Potential for Recovery of Test Facility Investment in Peace and in War

An excellent opportunity exists to recover test capability investments during peacetime through avoidance of test and schedule delays during acquisition, reduced requirements for flight testing, and prevention of aircraft losses during test and operations. The cost of new test capabilities might also be recovered by reducing weapon systems acquisition costs (e.g., less test flight hours, reduced procurement quantities). Another example is the potential to avoid a many of the software fixes that often occur during production and operation.

Figure 16 shows results of a study in which the median relative cost to fix an error during development test was found to be almost an order of magnitude lower than it was during operation. Thus very large savings accrue from discovering software errors early in an acquisition program. Ground testing in facilities such as an ISTF are the only means to test many of the parameters in the software for installed systems. Inasmuch as it is expected that software could be a significant cost for the F-22 or any new aircraft, the opportunities for cost avoidance through ISTF are substantial.



Source: Boehm, Barry W. "Software Risk Management." TRW, Inc., Washington, D.C., 1989, p. 3.

Figure 16. Escalation of Software Rework Costs with Phase

Being able to test war reserve modes thoroughly in a secure environment and improve crew responses in war scenarios likewise has potential for big returns on investment should war occur.

E. UNANSWERED TECHNICAL QUESTIONS

These questions do not figure in our analysis but

During the course ~~of our~~ investigation, several technical questions arose to which no answers were found. ~~Such questions~~ should be addressed when developing a program for a future large chamber construction at Patuxent River NAS ~~and~~ or when developing the upgrades to the existing large chamber at Edwards AFB. The questions are:

- How does one test multi-spectral systems? An answer is required before building a Category I installed systems test facility.
- Far-field signal generation versus signal-injection: How far is far enough? How many free-flow signal generators are needed to simulate reality? It is expected that injection techniques will also be needed and the AF should plan for that. (Further discussion of far-field testing is in Appendix G.)
- Can existing threat simulation models/capabilities around the country be moved to Edwards to upgrade the existing chamber? Savings accrue by using "standard" capabilities already proved.

At the request of DT&E, we also investigated whether the Grumman-operated anechoic chamber at Calverton, NY, could be used in lieu of additional facilities at Edwards or Patuxent River. The short answer is, "no." A discussion is included in Appendix G.

VIII. FINDINGS

This section presents a summary of the findings of our analyses.

A. INCREASING INSTALLED SYSTEMS TEST FACILITY CAPABILITY—PROS AND CONS

1. Current capability meets only 22% of stated Service electronic combat/avionics ISTF requirements.

2. Ground testing is the only way to do much EC testing. Reasons for this include:

   a. Security considerations.

   b. The number of test parameters.

   c. Ability to test earlier in the program and more safely.

3. Specific advantages of ISTFs over less capable facilities include five types of testing:

   a. Tests that require the test article to be installed in an aircraft in order to be evaluated.

   b. Tests that require levels of stimulation greater than those available in lesser facilities.

   c. Tests that require radiating elements to operate in an "in-flight" configuration.

   d. Tempest tests of specific installed hardware.

   e. Tests that require absolute security of RF signals, either threat or friendly. Examples of the types of testing uniquely appropriate to ISTFs are in Appendix G.

4. ISTF testing is cost-effective.

   a. Test facility costs are small relative to total systems acquisition costs. Testing makes acquisition decisions smarter and prevents delays and costly

retrofits that may be several orders of magnitude more costly to perform once production and fielding has taken place.

b. Both AF studies and IDA studies based on Navy data indicate ISTF development and operation may cost only one-eighth the cost of performing the same tests by flying. Three-fourths of software problems are said to be resolvable on the ground. Use of ISTFs minimizes the expensive fly-fix-fly approach to testing.

c. Ground testing is more efficient. It allows control of experiment and rapid repetition of test conditions. It reduces test costs and accelerates test schedules.

d. Ground testing allows more effective use of flight test time by focusing on risk areas. It makes flight testing and later operations safer, which may save the aircraft, crew, and mission, if problems are solved on the ground first .

5. These counter-arguments to more ISTF capability were also found:

a. Current workload data do not argue well for increases to capacity. ACETEF currently operates at 1.5 shifts but could go to 2.5. The BAF operates at less than 1 shift.

b. The DoD budget is declining. Future defense needs are uncertain.

B. USING AN IMPROVED ACETEF TO SATISFY AIR FORCE REQUIREMENTS—PROS AND CONS

1. Advantages of improving ACETEF include:

a. ACETEF is without question the best DoD ISTF for performing EC/avionics ground testing at the present time.

b. ACETEF has unused capacity now and can expand its operations with the least additional investment and operations costs.

c. ACETEF has the most competent and experienced EC/avionics ISTF test personnel—over 10 years of hands-on development of capability and test performance. In fact, ACETEF has the only proven capability in this area. The expertise to best support the F-22 resides at ACETEF.

2. Negatives regarding the choice of ACETEF for expansion and AF testing include:

a. The AF philosophy of testing is predicated on the close proximity of ground testing and flight testing (the Combined Test Force concept).

b. The Chesapeake Test Range at Patuxent NAS is considered to be too small and congested for additional high-performance AF flight testing.

c. AF requirements drive the need for additional ISTFs.

d. The cost of deploying the F-22 to ACETEF for electronic combat/avionics ground testing offsets the cost of developing an expanded ECIT at Edwards AFB.

e. Building ECIT would add more EC test capacity than expanding ACETEF, and at less cost per unit of added capacity.

C. DEVELOPING AN ISTF CAPABILITY AT EDWARDS AFB—PROS AND CONS

1. Advantages of improving ECIT include:

a. Edwards currently has the world's largest anechoic chamber, the BAF. This is the only current chamber with potential for far-field signal testing, testing multiple small aircraft and testing large aircraft.

b. Potential for any significant EC/avionics test capability using the BAF cannot be met without significant investment in supporting infrastructure.

c. The ECIT would be close to large and relatively uncongested ranges for EC and other flight testing. This fits the AF concept of single-site testing.

d. The Air Force has a wide variety of aircraft and missions that can benefit from testing in ISTF. All of these aircraft, many of which are larger than any in the Navy, are flight tested at Edwards. Development of an ECIT capability over time at the primary Air Force flight test center makes sense.

e. In conjunction with the small chamber already at ACETEF, building ECIT to support the BAF is more cost-effective than building a large chamber at Patuxent.

f. Building at Edwards would provide a second government source and competition for ISTF capability, and the stated requirements indicate the additional capacity is justified.

2. Negatives regarding ECIT include:

   a. The ECIT program plan is incomplete. We are not sure what specific funding levels might buy.

   b. Most of the work force for an ECIT has yet to be recruited and gain experience.

   c. It will be difficult for ECIT to be fully ready in time to support early testing in the F-22 schedule.

D. SUMMARY

The IDA analysis shows that building ECIT rather than a large chamber at ACETEF is the most cost-effective, lowest risk alternative. While both options would add the capability to test large aircraft, the ECIT at Edwards would provide the most flexibility to adjust to an uncertain workload and would add more total capacity at less cost per unit. It supports the current AF philosophy of collocating ground and flight testing, and provides a needed additional source of test capability. Further, it leverages the investments already made in the BAF and provides an opportunity to pursue the concept of far-field signal testing.

APPENDIX A

GENERIC ECIT COSTS AND FUNDING

APPENDIX A

GENERIC ECIT COSTS AND FUNDING

The Air Force provided a detailed cost estimate for developing the generic ECIT capability that was intended to satisfy the basic requirements of many different programs and serve as the foundation for building additional program-unique requirements. Such a generic type of capability is typically budgeted and funded using institutional funds of the responsible T&E organization or, in this particular case, the AF Flight Test Center at Edwards AFB.

During this study, we received documentation from and participated in discussions with various AF personnel about the technical content and cost of the generic ECIT capability. The generic capability was usually referred to as the "$60 million program." However, the briefings and supporting documentation we received did not adequately show a clear track between the various cost and funding profiles. Table A-1 is a summary of the different profiles.

Table A-1. Generic ECIT Program and Funding as of 1992 Budget Submission (Millions of FY 1992 Dollars)

	FY 92	FY 93	FY 94	FY 95	FY 96	FY 97	Total
Program Requirements							
Investment	7.8	14.2	12.9	7.5	7.7	3.2	53.3
Program Expenses	3.1	3.1	3.1	3.1	3.1	3.1	18.6
Total Generic ECIT Program	10.9	17.3	16.0	10.6	10.8	6.3	71.9
Funding							
Investment (PE 64735)	6.9	6.9	6.9	6.9	6.9	6.9	41.4
Program Management (PE 64735)	3.1	3.1	3.1	3.1	3.1	3.1	18.6
Subtotal (PE 64735)	10.0	10.0	10.0	10.0	10.0	10.0	60.0
Investment (PE 64755)	3.4	4.9					8.3
Subtotal (PEs 64735 & 64755)	13.4	14.9	10.0	10.0	10.0	10.0	68.3
Unfunded Requirements (Investment)	-2.4	2.4	6.0	0.7	0.8	-3.7	3.8
Total Generic ECIT Funding	11.0	17.3	16.0	10.7	10.8	6.3	72.1

Note: Slight differences between program requirements and funding are due to rounding.

In the program requirements section of the table, we show the AF estimate of the current ECIT program which totals about $72 million over a 6-year period. The program

consists of $53 million in investment assets (e.g., hardware and software) and $19 million in costs for managing the development and implementation of the ECIT program.

The funding section shows the approved program as contained in the FY 1992 President's Budget prior to the congressional cut that bought FY 1992 funding to zero. The "$60 million program" consists only of those costs budgeted in program element (PE) 64735, Range Improvements, to include investments of $41.4 million and program expenses of $18.6 million. There is an additional funding line representing investments for PE 64755, Development Test and Evaluation, of $8.3 million. This leaves a funding shortfall in investments of $3.8 million. The combined total of investments, program expenses, and unfunded investment requirements approximately equals the estimated AF costs of $72 million.

The IDA estimate of the cost of an ECIT capability equivalent to that programmed for ACETEF is about $168 million in constant FY 1992 dollars (see Table 9, Section VI). The shortfall of $100 million would be borne by programs requiring specific capabilities beyond the generic ones, notably the F-22. Coincidentally, this estimate is relatively consistent with amounts briefed by Edwards AFB on 5-6 February 1992. Officials at Edwards stated that some time earlier General Yates, Commander of AF Systems Command, had directed Edwards to program $60 million in internal Improvement and Modernization (I&M) funds for the generic capability, and that $90 million would be forthcoming from the system program offices for program-specific capabilities.

APPENDIX B

CONVERSION TO FY 1992 CONSTANT DOLLARS

APPENDIX B

CONVERSION TO FY 1992 CONSTANT DOLLARS

All then-year costs were converted to FY 1992 dollars for analytical purposes. Generally, this process is simple and straightforward. Annual costs in then-year dollars are converted to annual constant dollars by applying the appropriate DoD deflator for the specific appropriation and fiscal year. Unfortunately, the relevant costs for this study could not always be broken out by appropriation and/or fiscal year. As a result, we had to develop alternative methods for estimating costs in FY 1992 dollars. We used the standard DoD deflators (with FY 1992 as the base year) for total obligation authority (TOA) to compute 1992 base-year dollars. If the category description indicated that the cost was Military Construction (MILCON), we used the Navy or AF construction deflator. All other costs were converted using the Navy or AF RDT&E deflator.

NAVY COSTS

Table B-1 displays the original ACETEF costs as provided by the Navy, the data used to convert those costs to FY 1992 dollars, and the estimates expressed in FY 1992 dollars. The Navy provided ACETEF costs for existing, programmed (planned and approved), and planned but not approved functions and related facilities (column 1). Section IV describes these functions.

The cumulative cost totals for FY 1992, $249.45 million (column 2), and FY 1995, $397.35 million (column 4), were a mixture of then-year and constant dollars. For existing functions, some costs incurred in FY 1989 and prior were not segregated by function and fiscal year. For these costs ($88.4 million), we assumed they were incurred beginning with the opening of the anechoic chamber in 1983 and continuing in seven equal installments through 1989. Using the Navy-provided total then-year costs by function through 1992 (and 1995), we calculated the relative percentage for each of these functions, multiplied that percentage times the total 1989 costs, and divided that product by the average RDT&E deflator for 1983-1989 to produce $107.66 million in FY 1992 dollar costs for that period (column 7).

Table B-1. Constant FY 1992 Dollar Conversions (Millions)

	Through 92	Percentage Through 92	Through 95	Change	Percentage 93-5	FY 83-9	FY 90	FY 91	FY 92	Through 92	FY 93	FY 94	FY 95	FY 93-5	FY 83-95
[Deflators]						[.802][a]	[.923]	[.962]			[1.036]	[1.073]	[1.110]		
Functions															
EWISTL	14.95	0.11	26.40	11.45	0.18	12.14	1.92	1.50	1.76	17.33	3.07	3.37	4.19	10.63	27.96
ASEF	2.70	0.02	5.50	2.80	0.04	2.19	0.35	0.27	0.32	3.13	0.75	0.82	1.03	2.60	5.73
OCC	3.65	0.03	12.45	8.80	0.13	2.96	0.47	0.37	0.43	4.23	2.36	2.59	3.22	8.17	12.40
OSL	5.00	0.04	21.15	16.15	0.25	4.06	0.64	0.50	0.59	5.79	4.33	4.75	5.91	14.99	20.79
CNEL	8.30	0.06	16.45	8.15	0.13	6.74	1.07	0.83	0.98	9.62	2.18	2.40	2.98	7.57	17.19
CL	22.05	0.17	26.05	4.00	0.06	17.91	2.84	2.21	2.60	25.55	1.07	1.18	1.46	3.71	29.27
B3	26.10	0.20	29.85	3.75	0.06	21.20	3.36	2.62	3.07	30.25	1.00	1.10	1.37	3.48	33.73
MFS	49.80	0.38	59.90	10.10	0.15	40.45	6.41	5.00	5.86	57.71	2.71	2.97	3.70	9.38	67.09
Subtotal	132.55	1.00	197.75	65.20	1.00	107.66	17.05	13.30	15.60	153.61	17.46	19.20	23.87	60.53	214.14
Facilities															
LAC			68.00	68.00								68.00		68.00	68.00
SH-HGR	86.30		86.30	0.00						86.30					86.30
SAC	18.30		18.30	0.00						18.30					18.30
ASEF	12.30		12.30	0.00			13.25			13.25					13.25
[Deflators]							[.928146]								
NCTL			14.70	14.70								13.72		13.72	13.72
[Deflators]												[1.071]			
Subtotal	116.90		199.60	82.70			13.25			117.85	0.00	13.72	0.00	81.72	199.57
Total	249.45		397.35	147.90			30.31	13.30	15.60	271.46	17.46	32.92	23.87	142.25	413.71
[Type $]	[Mixed]		[Mixed]	[Mixed]		[FY 92]	[FY 92]	[FY 92]	[FY 92]	[FY 92]	[FY 92]	[FY 92]	[FY 92]	[FY 92]	[FY 92]

[a]1983, 0.727; 1984, 0.753; 1985, 0.776; 1986, 0.798; 1987, 0.822; 1988, 0.851; 1989, 0.886; average, 0.802..

Beginning in 1990, the Navy furnished individual fiscal year costs by source of funding (e.g., direct project support, I&M, CTEIP, etc.) but did not break them out by function (although facilities costs were subdivided). We took the annual funding (FY 1990, $15.75 million; FY 1991, $12.8 million; FY 1992, $15.6 million), multiplied each by the relative percentage for individual functions through FY 1992 and divided by the yearly RDT&E deflators for FY 1990 through FY 1992. We then added the FY 1989 cumulative amounts (column 7) and the individual FY 1990-92 amounts (columns 8, 9, and 10) to obtain $ 153.61 million in total costs through FY 1992 in FY 1992 dollars (column 11).

We computed the change in costs, $65.20 million, between functions for the 1992 and 1995 data submitted by the Navy (column 5). We then calculated the relative percentage change for each of the functions (column 6), multiplied that by the related funding for each fiscal year (FY 1993, $8.3 million; FY 1994, $20.6 million; FY 1995, $26.5 million), and divided by the appropriate annual RDT&E deflator to arrive at FY 1992 dollars (columns 12, 13, and 14). Like the Navy, we calculated total costs by function and facilities through FY 1992 and through FY 1995 of $271.46 million (column 11) and $413.71 million (column 16), respectively.

The Navy specified that the small anechoic chamber (SAC) and shielded hangar (SH) costs represented current replacement values. We accepted those amounts as equivalent FY 1992 dollars. The Navy also provided an estimate of $68 million for the proposed large anechoic chamber (LAC). We assumed this estimate to be in FY 1992 dollars because it agreed with our calculation using the last detailed Navy estimate of $58 million in FY 1988 dollars and adjusting for the Navy MILCON deflator. We also arbitrarily displayed the LAC amount in FY 1994 because the FY 1992 construction program is currently being executed and the President's FY 1993 budget submission has already been determined.

AIR FORCE COSTS

The AF estimates for the various ECIT functions and test deployment costs were in FY 1992 dollars. No conversion was required for these costs. However, the F-22 program office estimate of the deployment costs involved in testing at ACETEF rather than at ECIT was submitted in then-year dollars, and these costs were was converted to constant FY 1992 dollars using RDT&E deflators.

APPENDIX C

OPERATING COSTS

APPENDIX C

OPERATING COSTS

Operating costs represent the resources consumed in performing the routine and recurring tasks associated with ISTF function. The principal cost elements are labor, materiel (supplies and equipment) and facility support (e.g., utilities, security service, etc.). The dominant cost element is labor (both government and contractor personnel) that is required to develop the test capability and to perform the actual test function. The following subsections describe current and estimated future operating costs for the Navy's ACETEF capability and the AF's ECIT capability.

ACETEF OPERATING COSTS

The Navy did not provide us with a total cost estimate for operating the ACETEF facility on an annual basis. The Navy stated that available total costs included other support not related directly to anechoic chamber testing (e.g., work related to Strike aircraft) and that the costs we wanted could not be broken out and shown separately. However, the Navy was able to provide operating cost data for two laboratories and the chamber itself, manpower totals by ACETEF department, and marginal manpower estimates for increasing the number of shifts and expanding facilities.

Specifically, the Navy estimated the following FY 1993 operating costs in thousands of then-year dollars: Electronic Warfare Integrated Systems Test Laboratory (EWISTL) $580.3; manned flight simulator (MFS), $1,065.5; and the anechoic chamber, $420. We attempted to relate these costs with the number of government people assigned and to the asset values shown for these activities, in order to develop cost estimates for other capabilities. However, we were unable to identify any consistent relationships among the data and could not develop any other cost-estimating relationships.

The Navy currently operates an average of about 1.5 shifts per day annually at the ACETEF facility. The Navy estimated that no additional costs other than to programs would be incurred to support a 2.5 shift operation in existing facilities. The additional throughput would be achieved through revised scheduling of people and equipment. If the large anechoic chamber (LAC) were constructed, the Navy believed that an additional 12

government people would be required to operate the LAC and about another 10 test or laboratory personnel would be needed. Using the Navy estimate of $120 thousand for a fully loaded contractor work year, we estimated the marginal operating costs to be $2.64 million. These costs for 22 people would support two shifts each in the small and large chambers and the related four laboratory shifts. We estimated the cost of 20 full years of operations as 20 × $2.64 = $52.8 million plus an initial half year to bring up the operation ($1.3 million), $54.1 million in all.

ECIT OPERATING COSTS

The AF reported that the current annual costs to operate the Benefield Anechoic Facility (BAF) is approximately $5.5 million. This paid for 1 shift (8 hours daily, 5 days per week, 48 weeks per year) consisting of 5.25 hours test time and 2.75 hours for routine maintenance. The AF points out that this shift structure is not the preferred alternative but one that is largely driven by funding constraints. Table C-1 shows the major cost elements in the current BAF operating program. The largest element is labor, which represents almost 87% of the total program. Labor includes civilian pay, Engineering Technical Support Services contract, business management office overhead included in the contract, and award fee.

Table C-1. BAF Annual Operating Costs (Millions of FY 1992 Dollars)

Equipment (Over 15K)	35	0.6%
Civilian Pay	1,139	20.7%
Travel	25	0.5%
Equipment Maintenance	3	0.1%
Computer Maintenance	5	0.1%
Engineering Technical Support Services Contract	3,069	55.8%
Business Management Office Overhead (Contract)	295	5.4%
Award Fee	275	5.0%
Travel Administration	10	0.2%
Supplies	13	0.2%
Guard Service	352	6.4%
Administrative Supplies & Equipment	79	1.4%
Utilities	166	3.0%
Janitorial and Copying Services	34	0.6%
Total	5,500	100.0%

The AF notes that the more desirable shift approach would be a full 8 hours of testing followed by 8 hours of maintenance. Major periodic maintenance and facility/equipment upgrades were not included in the $5.5 million program. An increase to

2 shifts for testing alone would consist of 16 hours of testing and an additional 8 hours of routine maintenance. This would cost about $8 million. This scenario also delays periodic maintenance and upgrades.

The AF estimates that an additional $1.5 million to $1.9 million would be necessary to incorporate full periodic maintenance and upgrades in the desired shift configurations. Specifically, a total of $7 million would be required to run 1 full shift of testing and 1 full shift of full maintenance (routine and periodic and upgrades). A total of $9.9 million would be needed to perform 2 testing shifts and 1 full maintenance shift.

The AF indicated additional resources would depend on the specific aircraft system being tested and its particular testing requirements. Given that the AF intends to operate the BAF with or without ECIT, we did not consider the $5.5 million program to be a marginal cost. However, we included the additional $4.4 million needed to perform 2 test shifts and 1 maintenance shift ($9.9 million program) as an additional cost to operate the BAF in an ECIT configuration. We viewed this 3-shift combination to be the equivalent of the 2.5-shift ACETEF operation.

The $4.4 million in costs represent the additional costs to perform the actual testing. Additional personnel also are required to develop the test capability. In the absence of a specific AF estimate, we used the estimated number of government "developers" currently at ACETEF (45 personnel) that can support up to 2.5 shifts. We priced these 45 people at the fully loaded contractor rate of $130 thousand per man-year for a total of $6.85 million in additional costs. This included the annual program expenses of $3.1 million associated with the ECIT generic program, which contained "developer costs" during three years of the operating period (FY 1996-98). Total marginal operating costs were estimated at $11.25 million ($6.85 million + $3.75 million) to support the ECIT capability operating at 2.5 shifts. We estimated the total cost of 20 years of full-up operations to be 20 × $11.25 = $225 million, plus half a year of the $8.15 million to start operations, equals $229.1 million.

APPENDIX D

DEPLOYMENT COSTS

APPENDIX D

DEPLOYMENT COSTS

Experts generally agree that installed systems testing and flight testing are most efficiently and effectively accomplished at the same location. This permits the shared use of many of the same resources needed for both types of testing. When such testing is geographically separated, additional costs are usually incurred for moving test personnel and materiel (e.g., test articles, equipment, spares, etc.) to the new test site.

This section describes the methodology and estimated incremental costs that the Air Force ordinarily would incur if they were required to use the Navy's ACETEF facility rather than the ECIT facility at Edwards AFB where development flight testing will be performed. The methodology does not include any costs estimates for any additional materiel that may have to be procured, additional labor above what is already required, and possible schedule delays. The potential for these additional resource requirements varies by program and is included only in the F-22 estimates.

AF ESTIMATES

In its 14 January 1992 submission to OSD regarding the comparison of ECIT and ACETEF costs, the AF included estimated costs for various deployment scenarios. The AF identified 6 major categories of expense: travel, ground transportation, per diem, equipment shipments (by tactical and large), and aircraft fuel (also by tactical and large). These costs are dependent upon several key factors associated with test moves. Specifically, deployment costs are driven by the number of government and contractor people (group size), number (frequency) and duration of the deployments, the type of aircraft being used (tactical versus large) which largely determines the quantity of materiel moved and aircraft fuel used. The AF divided the factors into group sizes of small, medium, and large; into durations of short, intermediate, and long; and into frequencies of low, medium, and high.

APPLYING THE AIR FORCE ESTIMATES

We applied the AF deployment cost factors for various deployments of AF systems to ACETEF and Navy systems to ECIT as dictated by the alternatives. The methodology we employed is discussed in the next paragraph. An exception is the deployment estimates for the F-22 program where we had a more precise deployment schedule and a specific Service estimate. In addition to the AF estimate of the cost of F-22 deployment, we derived a less conservative and less costly one (the base case) from the AF estimate. We also developed a third estimate of F-22 deployment costs using the same methodology as for other systems. All three are shown in the paper, although we feel the base case is the most likely of the three. A discussion of methodology and detail used in estimating the cost of F-22 deployments follows that for other aircraft.

All Aircraft Deployments Other Than the F-22

Use of the AF deployment factors for all other aircraft systems would produce a wide range of possible costs for various deployment situations and make a detailed estimate by deployed system for all systems a cumbersome and time-consuming task unless a specific individual scenario could be identified. In the absence of this information, we elected to use a general approach that would approximate an "average" deployment.

Discussions with AF personnel revealed that, historically, a tactical aircraft typically would use a small group of people while a large aircraft was much more likely to use a medium or even a large group. However, given the projected increased demand for ISTF testing during the next several years, a medium group size would be reasonably representative of all aircraft systems.

In addition, short and intermediate durations were used because they closely reflected future requirements. A requirement was judged to be of short duration if less than 6 weeks. In the AF calculations, a short duration necessitates only one trip. A requirement of 6 weeks or more but less than 24 weeks was considered to be of intermediate duration. The AF intermediate duration allows for one round trip every four weeks.

Table D-1 summarizes the costs of deploying various AF aircraft to the ACETEF facility. We used the latest AF requirements for ISTF facilities as described in Section V, which totaled 127 weeks per year with an additional 27 weeks representing a 20% reserve. We then calculated the annual cost by aircraft system requirements that included the 20% reserve and applied one of two basic methods, average monthly and adjusted short.

Table D-1. Deployment Costs and Requirements

	Requirements (Weeks)	Requirements with 20% Reserve	Method	Annual Rate	Cost if Deployed (Thousands of FY 1992 Dollars)	Average Weekly Rate
Tactical (Special Case)						
F-22 (FY 1995-99)	21.0	25.2	Average Monthly	2,303.3	11,516.4 (5 years)	91.4
F-22 (FY 2000 on)	8.0	9.6	Average Monthly	1,015.0	15,225.0 (15 years)	102.8
Total 20-Year Cost					26,741.4	
Other Tactical					20-Year Cost	
EF-111	19.0	22.8	Average Monthly	1,323.2	26,463.4	
F-15	11.0	13.2	Average Monthly	766.0	15,320.9	
F-16	10.0	12.0	Average Monthly	696.4	13,928.1	
F-111	9.0	10.8	Average Monthly	626.8	12,535.3	
Total Other Tactical	49.0	58.8		3,412.4	68,247.7	58.0
Large						
B-1	3.0	3.6	Adjusted Short	354.2	7,084.0	
C-17	1.0	1.2	Adjusted Short	292.8	5,856.0	
C-130	1.0	1.2	Adjusted Short	292.8	5,856.0	
C-141	1.0	1.2	Adjusted Short	292.8	5,856.0	
AC-130U	6.0	7.2	Average Monthly	491.4	9,827.0	
EC-130	20.0	24.0	Average Monthly	1,637.8	32,756.8	
JSTARS	5.0	6.0	Average Monthly	409.5	8,189.2	
CV-22	12.0	14.4	Average Monthly	982.7	19,654.1	
E-3	5.0	6.0	Average Monthly	409.5	8,189.2	
MC-130CT	12.0	14.4	Average Monthly	982.7	19,654.1	
B-2	2.0	2.4	Adjusted Short	323.5	6,470.0	
Total Large	68.0	81.6		6,469.6	129,392.3	79.3
Total (without F-22)	117.0	140.4			197,640.0	
Total (with F-22)					224,381.4	

For the average monthly method, we took the average monthly cost for either a tactical or large aircraft (low frequency and intermediate duration), divided by 4 weeks to obtain the average weekly cost and multiplied by the number of weeks in the annual requirement to produce the average annual cost. The annual cost was multiplied by 20 to get the 20-year life-cycle cost estimate.

In the adjusted short (duration) method, we used the cost category data for the short duration as follows: Travel + Equipment Shipments + Fuel + Appropriate % (based on the relative number of weeks using the 2-week period as the base) of (Ground transportation + Per diem + Telephone/FAX).

We also showed the average weekly costs for the F-22 for both the five and 15-year periods, for tactical aircraft and for large aircraft.

F-22 Deployment Estimates

Table D-2 shows the estimate of additional costs the F-22 System Program Office (SPO) believes would be incurred should it be required to use the ACETEF facility (see Appendix F). The then-year dollar estimate of $357.6 million equates to $308.9 million in constant fiscal year 1992 budget dollars[1]. The only breakout furnished by the SPO is as shown in the tables. "SIL-Cat 1" includes the cost of basic set-up, support equipment, and instrumentation for two avionics lines at an F-22 systems integration laboratory (SIL) to be developed at Patuxent NAS. This SIL would support F-22 ACETEF testing only. "SIL-Cat 2" includes "the population of the facility with actual F-22 avionics hardware and associated spares." "SIL Ops" includes the cost of operating the SIL at Patuxent with 75 people. "Flight Ops" is the SPO estimate of the added costs occasioned by the loss of the use, while it is at Patuxent, of one F-22 test aircraft asset from the planned Edwards flight test program. Costs also include aircraft spares, and operations and support people at Patuxent, and the make-up of that part of the flight test program (26 months) that the aircraft at ACETEF would have flown had it been at Edwards. In addition, "a 25% allowance for regression and duplication test is assumed for test center-to-test center correlation." All SPO cost estimates include 15% for management reserve.

It appears that the System Program Office has attempted to minimize risk by treating all non-chamber ground testing at ACETEF as an add-on that would have to be replicated

1 IDA used constant FY92 budget year deflators for AF RDT&E as published by OASD (Comptroller), 17 January 1991.

elsewhere, e.g., at the IFAST at Edwards. Two avionics lines would be required at ACETEF. There are no offsetting savings for SIL work done at ACETEF that would not have to be done at IFAST. The SPO rationale for the cost estimate of flight testing states, "During the absence of the test asset, it is assumed that other avionics test assets would make up some of the lost flights, but no recoupment of the test time was considered due to the risk involved in that assumption." The lost time (26 months) of aircraft availability would be reaccomplished in FY 1998 and FY 1999 with the previously mentioned additional 25% for center-to-center correlation.

Table D-2. SPO Estimate of F-22 Deployment Costs

	1992	1993	1994	1995	1996	1997	1998	1999	2000	Total
Then-Year Dollars										
SIL-Cat 1		12.7	13.0							25.7
SIL-Cat 2	22.4	35.9	31.0							89.3
SIL Ops				20.5	21.2	21.9	22.5	23.3	6.0	115.4
Flight Ops							62.5	64.7		127.2
Total, F-22	22.4	48.6	44.0	20.5	21.2	21.9	85.0	88.0	6.0	357.6
FY 1992 Dollars										
SIL-Cat 1		12.3	12.1							24.4
SIL-Cat 2	22.4	34.6	28.9							85.9
SIL Ops				18.5	18.5	18.5	18.3	18.4	4.6	96.7
Flight Ops							50.9	51.0		101.9
Total, F-22	22.4	46.9	41.0	18.5	18.5	18.5	69.3	69.3	4.6	308.9

Note: Estimates include SIL with two avionics lines and 15% management reserve.

IDA believes the F-22 SPO estimate to be unnecessarily conservative, particularly since, in our view, the experience of the ACETEF personnel and the capabilities of the ACETEF facility, are unlikely to be matched anywhere else by the time planned for the start of F-22 EC/avionics ground testing in FY1995, even should the ECIT be built.

The IDA base case is based on the SPO deployment estimate, but accepts more risk. As shown in Table D-3, it first strips out the 15% Management Reserve in the SPO estimate. It allows a SIL at ACETEF, but with one avionics line. Our opinion is that a SIL collocated with the ISTF is desirable in as much as the F-22 is a new development with the first fully integrated EC/avionics subsystems.

Our rough estimate of the effect of going from two avionics lines to one line reduces the costs of the SPO's SIL Category 1 and SIL Operations by a third, and SIL Category 2 by half. For flight operations, we rejected the 25% add-on for center-to-center correlation, and assumed half the flights could be made up by the avionics test aircraft remaining at Edwards. This results in a 60% reduction in the SPO estimate for additional flight operations. The estimate of the total cost through FY 2000 in this scenario is $143

million constant FY 1992 budget dollars, roughly half the SPO estimate. The detail is shown in Table D-3.

Table D-3. Derivation of IDA Estimate of F-22 Deployment Costs

	1992	1993	1994	1995	1996	1997	1998	1999	2000	Total
Two lines (less or without 15%)										
Then-Year $—SPO										
SIL-Cat 1		11.0	11.3							22.3
SIL-Cat 2	19.5	31.2	27.0							77.7
SIL Ops				17.8	18.4	19.0	19.6	20.3	5.2	100.3
Flight Ops							54.3	56.3		110.6
Total, F-22	19.5	42.3	38.3	17.8	18.4	19.0	73.9	76.5	5.2	311.0
FY 1992 $—SPO										
SIL-Cat 1		10.7	10.5							21.2
SIL-Cat 2	19.5	30.1	25.1							74.7
SIL Ops				16.1	16.1	16.0	15.9	16.0	4.0	84.0
Flight Ops							44.3	44.3		88.6
Total, F-22	19.5	40.8	35.7	16.1	16.1	16.0	60.2	60.3	4.0	268.6
One Line (less or without 15%)										
FY 1992 $—IDA										
SIL-Cat 1		7.1	7.0							14.1
SIL-Cat 2	9.7	15.1	12.6							37.4
SIL Ops				10.7	10.7	10.7	10.6	10.6	2.7	56.0
Flight Ops							20.4	20.4		40.8
Total, F-22	9.7	22.2	19.6	10.7	10.7	10.7	31.0	31.0	2.7	148.3

There are two sensitivity analyses. One uses the Air Force estimate of the cost of F-22 deployments, as shown in Table D-2 in constant FY 1992 budget year dollars. The second assumes that the F-22 could use the same technique for deployment to ACETEF as was used by other AF systems such as the F-16 and the EC-130, i.e., a standard deployment with no SIL, no extra spares, etc. The estimated cost of $11 million over the years FY 1992 to FY 2000 is spread as shown in Table D-4, and is based on a typical AF large group (49 people), deployment costs for 24 weeks per year for FY 1995 through FY 1999, and 12 weeks per year thereafter. These time periods include 20% reserve. The methodology employed is the same as that detailed in Section V of the paper.

Table D-4. Minimum F-22 Deployment Costs

	1992	1993	1994	1995	1996	1997	1998	1999	2000 and Beyond
Weeks Deployed				20.0	20.0	20.0	20.0	20.0	10.0
With +20%				24.0	24.0	24.0	24.0	24.0	12.0
@ $91.4K/week	0.2	0.3	1.9	1.9	1.9	1.9	1.9		1.0
Total, FY 1992-2000									11.0

APPENDIX E

SENSITIVITY ANALYSES: REQUIREMENTS, COSTS, AND MEASURES OF MERIT

APPENDIX E

SENSITIVITY ANALYSES: REQUIREMENTS, COSTS, AND MEASURES OF MERIT

This appendix provides the results of our sensitivity analyses made by varying F-22 deployment costs and changing service test requirements. First, we examine the base case (100% of the services' electronic combat test requirements that use installed systems test facilities) in terms of needs and costs, using three different cost estimates for F-22 deployment. We also examine the base case with varying F-22 deployment costs, but considers them from the perspective of measures of merit. Next, we show cost and needs and measures of merit results when demand is changed to various levels between 50% and 150% of the 100% base case. Finally, we summarize the overall results.

NEEDS AND COSTS

The columns in Tables E-1 through E-6 (all the tables appear together at the end of the appendix) show four measures of merit: (1) capabilities ("Percent of Needs Met"), (2) effectiveness ("Increase in Needs Met"), (3) "Additive Costs", and (4) measure of effectiveness ("Cost per Percent of Needs Met"). In each of these tables, the results assume a demand equal to 100% of the stated requirement. The various rows correspond to the current situation at ACETEF and each of the four alternatives in the study.

Table E-1 shows the results for the base case (which uses the IDA estimate for F-22 deployment) when discounted FY 1992 dollars are used. Table E-2 shows the same conditions for undiscounted constant FY 1992 dollars. As indicated in both tables, Alternative 4 is best in capability, effectiveness, and measure of effectiveness, and poorest in additive cost. (Coincidentally the order of alternatives also shows their monotonically increasing or decreasing alignment in this Base Case.) If one looks at the primary alternatives of interest, 2 and 3, the cost of the alternative in which ECIT is developed and used (Alternative 3), is estimated to cost 7% more than the cost of developing and using a large anechoic chamber at ACETEF (Alternative 2). However, the cost per percent of additional needs met with ECIT is 25% less than the ACETEF/LAC alternative due to the 43% increase in capability with the ECIT option.

Results obtained from using the deployment estimate of the F-22 SPO, rather than that of IDA are shown in Tables E-3 (discounted constant dollars) and E-4 (constant dollars). Using the SPO estimate increases the costs of Alternatives 1 and 2 substantially. Now the least-cost alternative is 3 (ECIT), and it would be less costly to build both the LAC and ECIT (Alternative 4) than to build the LAC alone (Alternative 2). (This is because the F-22 deployment costs more than offset the cost of ECIT but would be foregone in Alternative 4.) Between Alternatives 2 and 3, the alternative with ECIT is now 75% of the cost of that with LAC, and the cost per percent of additional needs met with ECIT is 53% of that with LAC.

The results using the minimal deployment estimates are shown in Tables E-5 and E-6. Even though the cost of building and operating both ECIT and a LAC (Alternative 4) is almost twice as much as that for LAC alone (Alternative 2), the cost per percent of added needs met for Alternative 4 is slightly better than for Alternative 2.

MEASURES OF MERIT

If one assigns a 1 to the "best" alternative and a "4" to the worst in each category, the rankings for the IDA deployment estimate are shown in Tables E-7 and E-8 for discounted and constant dollars, respectively. (The basic data correspond to Tables E-1 and E-2, respectively.) In this set of tables, the capabilities column has been dropped, but columns showing "Unquantifiable" and "Total" have been added. "Unquantifiable" is our subjective overall assessment of the various alternatives in areas such as: potential to meet surges in workload, meeting current test philosophies, avoiding risk in weapons system acquisition, etc. "Total" is the sum across columns for each alternative and is based upon equal weight assigned to each category. A decision maker could change this assumption and weight the various measures of merit differently. The alternative with the lowest total score is best. For the base case shown in Tables E-7 and E-8, Alternatives 4 and 3 are ranked first and second, respectively. When the F-22 SPO deployment estimate is substituted for that of IDA, the rankings that result (Tables E-9 and E-10) are the same as in the base case, with Alternatives 4 and 3 being the most highly rated.

When the minimum deployment estimate is substituted for that of IDA, Alternative 4 remains best in the total ranking, but Alternative 2, that of building a large anechoic chamber adjacent to ACETEF, ties with Alternative 3 if discounted dollars are used (Table E-11), and is superior to Alternative 3 in constant dollars (Table E-12).

RESULTS FROM VARYING REQUIREMENTS

Tables E-13 through E-24 are in the same order as those described previously, but use only 75% of the stated requirement. For the IDA and F-22 SPO deployment estimates (Tables E-13 through E-16, E-19 through E-22), Alternative 3 (ECIT) ranks best and Alternative 4 second best. This is a reversal of their order with 100% of the test requirement, because there is now excess capacity in Alternative 4. When the minimum deployment cost estimate is used with 75% of the requirement and discounted dollars (Tables E-17 and E-23), the best ranking is with Alternative 2 (build large chamber at Patuxent) followed by Alternative 1. In constant dollars (Tables E-18 and E-24), the best ranking under minimal deployment costs and 75% of the stated test requirement, is Alternative 2 (no new chamber) followed by a tie for second best between Alternatives 3 and 4.

Tables E-25 through E-36 present data similar to those described above when only 50% of the stated requirement is used. Only with the F-22 SPO deployment estimate (Tables E-27, E-28, E-33, and E-34), does Alternative 3 rank best and Alternative 4 second best. With the IDA estimate in constant dollars and 50% of the test requirement (Tables E-26 and E-32), and with the IDA estimate discounted (Tables E-25 and E-31), the rankings of Alternatives 2 and 3 are equivalent. When the minimum deployment cost estimate is used with 50% of the requirement (Tables E-29, E-30, E-35 and E-36), the rankings of all alternatives are equivalent whether or not constant or discounted dollars are used.

For increases in requirements (Tables E-37 through E-48 at 125% of the stated, and E-49 through E-60 at 150%) the relative rank order does not change from comparable deployment cost-estimating assumptions at 100%. Alternative 4 (do both) is best, followed by Alternative 3 (ECIT).

SUMMARY

Table E-61 shows in a single table all the preferred alternatives discussed above. The columns show ranking results of the various sensitivity excursions in requirements. The rows are the variations in deployment cost, with two measures of merit for each. We believe the most important single measure of merit is "dollars per additional requirement met." The second measure of merit is the aggregated, equal-weight "total" category discussed above. The best and second-best alternatives for each of these two categories is shown for all cases.

Table E-61 shows that for any special deployment of the F-22, Alternative 4 dominates under requirements of 100% or more. Alternative 3 is second best under these full-requirement options, and is first at 75% of the stated requirement. We think these options to be most likely. Alternative 2 is best for a mid-range deployment option only for 50% of the test requirement. If a minimum deployment cost is used, Alternative 4 still dominates for cases of 100% or more, but Alternative 2 is second best, and comes to dominate for 75%. At 50% of the requirement with minimum deployment cost, the first alternative ranks best in least cost per unit of additional requirement met even though no large chamber requirements are met; however, in total points all alternatives are equal.

Table E-1. Needs and Constrained Costs with IDA Deployment Estimate (Discounted FY 1992 Dollars in Millions)

	Description of Alternative	Percent of Needs Met	Increase in Needs Met	Additive Costs[a]	Cost Per Percent of Added Needs Met
0	Baseline ACETEF	22%	0%	$50	NA
1	Provide 2.5 Shifts at ACETEF	36%	14%	$167	$11.9
2	Build LAC at Patuxent with 4-Shift Capacity	57%	35%	$249	$7.1
3	Build ECIT at Edwards (and Alt. 1 ACETEF)	72%	50%	$264	$5.3
4	Build LAC and ECIT (Alt. 2 + Alt.3)	94%	72%	$328	$4.6

[a] Uses IDA estimate with fiscally constrained F-22 deployment. Costs include future investments, 20-years of operations and deployments. FY 1992 dollars are discounted at 10% per annum.

Table E-2. Needs and Constrained Costs with IDA Deployment Estimate (Constant FY 1992 Dollars in Millions)

	Description of Alternative	Percent of Needs Met	Increase in Needs Met	Additive Costs[a]	Cost Per Percent of Added Needs Met
0	Baseline ACETEF	22%	0%	$60	NA
1	Provide 2.5 Shifts at ACETEF	36%	14%	$262	$18.7
2	Build LAC at Patuxent with 4-Shift Capacity	57%	35%	$454	$13.0
3	Build ECIT at Edwards (and Alt. 1 ACETEF)	72%	50%	$486	$9.7
4	Build LAC and ECIT (Alt. 2 + Alt.3)	94%	72%	$589	$8.2

[a] Uses IDA estimate with fiscally constrained F-22 deployment. Costs include future investments, 20-years of operations and deployments. Constant FY 1992 dollars are undiscounted.

Table E-3. Needs and Unconstrained Costs with F-22 SPO Deployment Estimate (Discounted FY 1992 Dollars in Millions)

	Description of Alternative	Percent of Needs Met	Increase in Needs	Additive Costs[a]	Cost Per Percent of Added Needs Met
0	Baseline ACETEF	22%	0%	$50	NA
1	Provide 2.5 Shifts at ACETEF	36%	14%	$281	$20.1
2	Build LAC at Patuxent with 4-Shift Capacity	57%	35%	$352	$10.1
3	Build ECIT at Edwards (and Alt. 1 ACETEF)	72%	50%	$264	$5.3
4	Build LAC and ECIT (Alt. 2 + Alt.3)	94%	72%	$328	$4.6

[a] Uses SPO estimate with fiscally unconstrained F-22 deployment. Costs include *future* investments, 20-years of operations and deployments. FY 1992 dollars are discounted at 10% per annum.

Table E-4. Needs and Unconstrained Costs with F-22 SPO Deployment Estimate (Constant FY 1992 Dollars in Millions)

	Description of Alternative	Percent of Needs Met	Increase in Needs Met	Additive Costs[a]	Cost Per Percent of Added Needs Met
0	Baseline ACETEF	22%	0%	$60	NA
1	Provide 2.5 Shifts at ACETEF	36%	14%	$428	$30.6
2	Build LAC at Patuxent with 4-Shift Capacity	57%	35%	$620	$17.7
3	Build ECIT at Edwards (and Alt. 1 ACETEF)	72%	50%	$486	$9.7
4	Build LAC and ECIT (Alt. 2 + Alt.3)	94%	72%	$589	$8.2

[a] Uses SPO estimate with fiscally unconstrained F-22 deployment. Costs include future investments, 20-years of operations and deployments. Constant FY 1992 dollars are not discounted.

Table E-5. Needs and Minimum Costs with Minimum Deployment Estimate (Discounted FY 1992 Dollars in Millions)

	Description of Alternative	Percent of Needs Met	Increase in Needs Met	Additive Costs[a]	Cost Per Percent of Added Needs Met
0	Baseline ACETEF	22%	0%	$50	NA
1	Provide 2.5 Shifts at ACETEF	36%	14%	$75	$5.4
2	Build LAC at Patuxent with 4-Shift Capacity	57%	35%	$165	$4.7
3	Build ECIT at Edwards (and Alt. 1 ACETEF)	72%	50%	$264	$5.3
4	Build LAC and ECIT (Alt. 2 + Alt.3)	94%	72%	$328	$4.6

[a] Uses minimum deployment estimate with F-22 deployed with no additional SIL or flight testing. Costs include future investments, 20-years of operations and deployments. FY 1992 dollars discounted at 10% per annum.

Table E-6. Needs and Minimum Costs with Minimum Deployment Estimate (Constant FY 1992 Dollars in Millions)

	Description of Alternative	Percent of Needs Met	Increase in Needs Met	Additive Costs[a]	Cost Per Percent of Added Needs Met
0	Baseline ACETEF	22%	0%	$60	NA
1	Provide 2.5 Shifts at ACETEF	36%	14%	$132	$9.4
2	Build LAC at Patuxent with 4-Shift Capacity	57%	35%	$324	$9.3
3	Build ECIT at Edwards (and Alt. 1 ACETEF)	72%	50%	$486	$9.7
4	Build LAC and ECIT (Alt. 2 + Alt.3)	94%	72%	$589	$8.2

[a] Uses minimum deployment estimate with F-22 deployed with no additional SIL or flight testing. Costs include future investments, 20-years of operations and deployments. FY 1992 constant dollars are not discounted

Table E-7. Measures of Merit with IDA Deployment Estimate (Discounted FY 1992 Dollars in Millions)

	Description of Alternative	Increase in Needs Met	Additive Costs[a]	Cost Per Percent of Added Needs Met	Unquanti-fiable	Total[b]
1	Provide 2.5 Shifts at ACETEF	4	1	4	4	13
2	Build LAC at Patuxent with 4-Shift Capacity	3	2	3	3	11
3	Build ECIT at Edwards (and Alt. 1 ACETEF)	2	3	2	2	9
4	Build LAC and ECIT (Alt. 2 + Alt.3)	1	4	1	1	7

[a] Uses IDA estimate with fiscally constrained F-22 deployment. Costs include future investments, 20-years of operations and deployments. FY 1992 dollars are discounted at 10% per annum.

[b] All categories equally weighted. Lowest score is best alternative.

Table E-8. Measures of Merit with IDA Deployment Estimate (Constant FY 1992 Dollars in Millions)

	Description of Alternative	Increase in Needs Met	Additive Costs[a]	Cost Per Percent of Added Needs Met	Unquanti-fiable	Total[b]
1	Provide 2.5 Shifts at ACETEF	4	1	4	4	13
2	Build LAC at Patuxent with 4-Shift Capacity	3	2	3	3	11
3	Build ECIT at Edwards (and Alt. 1 ACETEF)	2	3	2	2	9
4	Build LAC and ECIT (Alt. 2 + Alt.3)	1	4	1	1	7

[a] Uses IDA estimate with fiscally constrained F-22 deployment. Costs include future investments, 20-years of operations and deployments. Constant FY 1992 dollars are undiscounted.

[b] All categories equally weighted. Lowest score is best alternative.

Table E-9. Measures of Merit with F-22 SPO Deployment Estimate (Discounted FY 1992 Dollars in Millions)

	Description of Alternative	Increase in Needs Met	Additive Costs[a]	Cost Per Percent of Added Needs Met	Unquanti-fiable	Total[b]
1	Provide 2.5 Shifts at ACETEF	4	2	4	4	14
2	Build LAC at Patuxent with 4-Shift Capacity	3	4	3	3	13
3	Build ECIT at Edwards (and Alt. 1 ACETEF)	2	1	2	2	7
4	Build LAC and ECIT (Alt. 2 + Alt. 3)	1	3	1	1	6

[a] Uses SPO estimate with fiscally unconstrained F-22 deployment. Costs include future investments, 20-years of operations and deployments. FY 1992 dollars are discounted at 10% per annum.

[b] All categories equally weighted. Lowest score is best alternative.

Table E-10. Measures of Merit with F-22 SPO Deployment Estimate (Constant FY 1992 Dollars in Millions)

	Description of Alternative	Increase in Needs Met	Additive Costs[a]	Cost Per Percent of Added Needs Met	Unquanti-fiable	Total[b]
1	Provide 2.5 Shifts at ACETEF	4	1	4	4	13
2	Build LAC at Patuxent with 4-Shift Capacity	3	4	3	3	13
3	Build ECIT at Edwards (and Alt. 1 ACETEF)	2	2	2	2	8
4	Build LAC and ECIT (Alt. 2 + Alt. 3)	1	3	1	1	6

[a] Uses SPO estimate with fiscally unconstrained F-22 deployment. Costs include future investments, 20-years of operations and deployments. Constant FY 1992 dollars are not discounted.

[b] All categories equally weighted. Lowest score is best alternative.

Table E-11. Measures of Merit with Minimum Deployment Estimate (Discounted FY 1992 Dollars in Millions)

	Description of Alternative	Increase in Needs Met	Additive Costs[a]	Cost Per Percent of Added Needs Met	Unquanti-fiable	Total[b]
1	Provide 2.5 Shifts at ACETEF	4	1	4	4	13
2	Build LAC at Patuxent with 4-Shift Capacity	3	2	2	3	10
3	Build ECIT at Edwards (and Alt. 1 ACETEF)	2	3	3	2	10
4	Build LAC and ECIT (Alt. 2 + Alt. 3)	1	4	1	1	7

[a] Uses minimum deployment estimate with F-22 deployed with no additional SIL or flight testing. Costs include future investments, 20-years of operations and deployments. FY 1992 dollars discounted at 10% per annum.

[b] All categories equally weighted. Lowest score is best alternative.

Table E-12. Measures of Merit with Minimum Deployment Estimate (Constant FY 1992 Dollars in Millions)

	Description of Alternative	Increase in Needs Met	Additive Costs[a]	Cost Per Percent of Added Needs Met	Unquanti-fiable	Total[b]
1	Provide 2.5 Shifts at ACETEF	4	1	3	4	12
2	Build LAC at Patuxent with 4-Shift Capacity	3	2	2	3	10
3	Build ECIT at Edwards (and Alt. 1 ACETEF)	2	3	4	2	11
4	Build LAC and ECIT (Alt. 2 + Alt. 3)	1	4	1	1	7

[a] Uses minimum deployment estimate with F-22 deployed with no additional SIL or flight testing. Costs include future investments, 20-years of operations and deployments. FY 1992 constant dollars are not discounted.

[b] All categories equally weighted. Lowest score is best alternative.

Table E-13. Needs and Constrained Costs with IDA Deployment Estimate 75% of Stated Requirement (Discounted FY 1992 Dollars in Millions)

	Description of Alternative	Percent of Needs Met	Increase in Needs Met	Additive Costs[a]	Cost Per Percent of Added Needs Met
0	Baseline ACETEF	29%	0%	$50	NA
1	Provide 2.5 Shifts at ACETEF	48%	19%	$167	$8.9
2	Build LAC at Patuxent with 4-Shift Capacity	76%	47%	$249	$5.3
3	Build ECIT at Edwards (and Alt. 1 ACETEF)	96%	67%	$283	$4.2
4	Build LAC and ECIT (Alt. 2 + Alt.3)	100%	78%	$323	$4.6

[a] Uses IDA estimate with fiscally constrained F-22 deployment. Costs include future investments, 20-years of operations and deployments. FY 1992 dollars are discounted at 10% per annum.

Table E-14. Needs and Constrained Costs with IDA Deployment Estimate 75% of Stated Requirement (Constant FY 1992 Dollars in Millions)

	Description of Alternative	Percent of Needs Met	Increase in Needs Met	Additive Costs[a]	Cost Per Percent of Added Needs Met
0	Baseline ACETEF	29%	0%	$60	NA
1	Provide 2.5 Shifts at ACETEF	48%	19%	$262	$14.0
2	Build LAC at Patuxent with 4-Shift Capacity	76%	47%	$454	$9.7
3	Build ECIT at Edwards (and Alt. 1 ACETEF)	96%	67%	$527	$7.9
4	Build LAC and ECIT (Alt. 2 + Alt.3)	100%	78%	$577	$8.2

[a] Uses IDA estimate with fiscally constrained F-22 deployment. Costs include future investments, 20-years of operations and deployments. FY 1992 dollars are not discounted.

Table E-15. Needs and Constrained Costs with F-22 SPO Deployment Estimate 75% of Stated Requirement (Discounted FY 1992 Dollars in Millions)

	Description of Alternative	Percent of Needs Met	Increase in Needs Met	Additive Costs[a]	Cost Per Percent of Added Needs Met
0	Baseline ACETEF	29%	0%	$50	NA
1	Provide 2.5 Shifts at ACETEF	48%	19%	$281	$15.1
2	Build LAC at Patuxent with 4-Shift Capacity	76%	47%	$352	$7.5
3	Build ECIT at Edwards (and Alt. 1 ACETEF)	96%	67%	$283	$4.2
4	Build LAC and ECIT (Alt. 2 + Alt.3)	100%	78%	$323	$4.6

[a] Uses SPO estimate with fiscally unconstrained F-22 deployment. Costs include future investments, 20-years of operations and deployments. FY 1992 dollars are discounted at 10% per annum.

Table E-16. Needs and Constrained Costs with F-22 SPO Deployment Estimate 75% of Stated Requirement (Constant FY 1992 Dollars in Millions)

	Description of Alternative	Percent of Needs Met	Increase in Needs Met	Additive Costs[a]	Cost Per Percent of Added Needs Met
0	Baseline ACETEF	29%	0%	$60	NA
1	Provide 2.5 Shifts at ACETEF	48%	19%	$428	$22.9
2	Build LAC at Patuxent with 4-Shift Capacity	76%	47%	$620	$13.3
3	Build ECIT at Edwards (and Alt. 1 ACETEF)	96%	67%	$527	$7.9
4	Build LAC and ECIT (Alt. 2 + Alt.3)	100%	78%	$577	$8.2

[a] Uses SPO estimate with fiscally unconstrained F-22 deployment. Costs include future investments, 20-years of operations and deployments. Constant FY 1992 dollars are not discounted.

Table E-17. Needs and Constrained Costs with Minimum Deployment Estimate 75% of Stated Requirement (Discounted FY 1992 Dollars in Millions)

	Description of Alternative	Percent of Needs Met	Increase in Needs Met	Additive Costs[a]	Cost Per Percent of Added Needs Met
0	Baseline ACETEF	29%	0%	$50	NA
1	Provide 2.5 Shifts at ACETEF	48%	19%	$75	$4.0
2	Build LAC at Patuxent with 4-Shift Capacity	76%	47%	$165	$3.5
3	Build ECIT at Edwards (and Alt. 1 ACETEF)	96%	67%	$283	$4.2
4	Build LAC and ECIT (Alt. 2 + Alt.3)	100%	78%	$323	$4.6

[a] Uses minimum deployment estimate with F-22 deployed with no additional SIL or flight testing. Costs include future investoments, 20-years of operations and deployments. FY 1992 dollars discounted at 10% per annum.

Table E-18. Needs and Constrained Costs with Minimum Deployment Estimate 75% of Stated Requirement (Constant FY 1992 Dollars in Millions)

	Description of Alternative	Percent of Needs Met	Increase in Needs Met	Additive Costs[a]	Cost Per Percent of Added Needs Met
0	Baseline ACETEF	29%	0%	$60	NA
1	Provide 2.5 Shifts at ACETEF	48%	19%	$132	$7.1
2	Build LAC at Patuxent with 4-Shift Capacity	76%	47%	$324	$6.9
3	Build ECIT at Edwards (and Alt. 1 ACETEF)	96%	67%	$527	$7.9
4	Build LAC and ECIT (Alt. 2 + Alt.3)	100%	78%	$577	$8.2

[a] Uses minimum deployment estimate with F-22 deployed with no additional SIL or flight testing. Costs include future investments, 20-years of operations and deployments. FY 1992 constant dollars are not discounted.

Table E-19. Measures of Merit with IDA Deployment Estimate 75% of Stated Requirement, (Discounted FY 1992 Dollars in Millions)

	Description of Alternative	Increase in Needs Met	Additive Costs[a]	Cost Per Percent of Added Needs Met	Unquantifiable	Total[b]
1	Provide 2.5 Shifts at ACETEF	4	1	4	4	13
2	Build LAC at Patuxent with 4-Shift Capacity	3	2	3	3	11
3	Build ECIT at Edwards (and Alt. 1 ACETEF)	2	3	1	2	8
4	Build LAC and ECIT (Alt. 2 + Alt.3)	1	4	2	1	8

[a] Uses IDA estimate with fiscally constrained F-22 deployment. Costs include future investments, 20-years of operations and deployments. FY 1992 dollars are discounted at 10% per annum.

[b] All categories equally weighted. Lowest score is best alternative.

Table E-20. Measures of Merit with IDA Deployment Estimate 75% of Stated Requirement (Constant FY 1992 Dollars in Millions)

	Description of Alternative	Increase in Needs Met	Additive Costs[a]	Cost Per Percent of Added Needs Met	Unquantifiable	Total[b]
1	Provide 2.5 Shifts at ACETEF	4	1	4	4	13
2	Build LAC at Patuxent with 4-Shift Capacity	3	2	3	3	11
3	Build ECIT at Edwards (and Alt. 1 ACETEF)	2	3	1	2	8
4	Build LAC and ECIT (Alt. 2 + Alt.3)	1	4	2	1	8

[a] Uses IDA estimate with fiscally constrained F-22 deployment. Costs include future investments, 20-years of operations and deployments. Constant FY 1992 dollars are not discounted.

[b] All categories equally weighted. Lowest score is best alternative.

Table E-21. Measures of Merit with F-22 SPO Deployment Estimate 75% of Stated Requirement, (Discounted FY 1992 Dollars in Millions)

	Description of Alternative	Increase in Needs Met	Additive Costs[a]	Cost Per Percent of Added Needs Met	Unquantifiable	Total[b]
1	Provide 2.5 Shifts at ACETEF	4	2	1	4	13
2	Build LAC at Patuxent with 4-Shift Capacity	3	4	3	3	13
3	Build ECIT at Edwards (and Alt. 1 ACETEF)	2	1	2	2	7
4	Build LAC and ECIT (Alt. 2 + Alt.3)	1	3	2	1	7

[a] Uses SPO estimate with fiscally unconstrained F-22 deployment. Costs include future investments, 20-years of operations and deployments. FY 1992 dollars are discounted at 10% per annum.

[b] All categories equally weighted. Lowest score is best alternative.

Table E-22. Measures of Merit with F-22 SPO Deployment Estimate 75% of Stated Requirement, (Constant FY 1992 Dollars in Millions)

	Description of Alternative	Increase in Needs Met	Additive Costs[a]	Cost Per Percent of Added Needs Met	Unquantifiable	Total[b]
1	Provide 2.5 Shifts at ACETEF	4	1	4	4	13
2	Build LAC at Patuxent with 4-Shift Capacity	3	4	3	3	13
3	Build ECIT at Edwards (and Alt. 1 ACETEF)	2	2	1	2	7
4	Build LAC and ECIT (Alt. 2 + Alt.3)	1	3	2	1	7

[a] Uses SPO estimate with fiscally unconstrained F-22 deployment. Costs include future investments, 20-years of operations and deployments. Constant FY 1992 dollars are not discounted.

[b] All categories equally weighted. Lowest score is best alternative.

Table E-23. Measures of Merit with Minimum Deployment Estimate 75% of Stated Requirement, (Discounted FY 1992 Dollars in Millions)

	Description of Alternative	Increase in Needs Met	Additive Costs[a]	Cost Per Percent of Added Needs Met	Unquanti-fiable	Total[b]
1	Provide 2.5 Shifts at ACETEF	4	1	2	4	11
2	Build LAC at Patuxent with 4-Shift Capacity	3	2	1	3	9
3	Build ECIT at Edwards (and Alt. 1 ACETEF)	2	3	3	2	10
4	Build LAC and ECIT (Alt. 2 + Alt.3)	1	4	4	1	10

[a] Uses minimum deployment estimate with F-22 deployed with no additional SIL or flight testing. Costs include future investments, 20-years of operations and deployments. FY 1992 dollars discounted at 10% per annum.

[b] All categories equally weighted. Lowest score is best alternative.

Table E-24. Measures of Merit with Minimum Deployment Estimate 75% of Stated Requirement, (Constant FY 1992 Dollars in Millions)

	Description of Alternative	Increase in Needs Met	Additive Costs[a]	Cost Per Percent of Added Needs Met	Unquanti-fiable	Total[b]
1	Provide 2.5 Shifts at ACETEF	4	1	2	4	11
2	Build LAC at Patuxent with 4-Shift Capacity	3	2	1	3	9
3	Build ECIT at Edwards (and Alt. 1 ACETEF)	2	3	3	2	10
4	Build LAC and ECIT (Alt. 2 + Alt.3)	1	4	4	1	10

[a] Uses minimum deployment estimate with F-22 deployed with no additional SIL or flight testing. Costs include future investments, 20-years of operations and deployments. Constant FY 1992 dollars are not discounted.

[b] All categories equally weighted. Lowest score is best alternative.

Table E-25. Needs and Constrained Costs with IDA Deployment Estimate 50% of Stated Requirement (Discounted FY 1992 Dollars in Millions)

	Description of Alternative	Percent of Needs Met	Increase in Needs Met	Additive Costs[a]	Cost Per Percent of Added Needs Met
0	Baseline ACETEF	44%	0%	$50	NA
1	Provide 2.5 Shifts at ACETEF	72%	28%	$163	$5.8
2	Build LAC at Patuxent with 4-Shift Capacity	100%	56%	$243	$4.3
3	Build ECIT at Edwards (and Alt. 1 ACETEF)	100%	56%	$278	$5.0
4	Build LAC and ECIT (Alt. 2 + Alt.3)	100%	72%	$323	$5.8

[a] Uses IDA estimate with fiscally constrained F-22 deployment. Costs include future investments, 20-years of operations and deployments. FY 1992 dollars are discounted at 10% per annum.

Table E-26. Needs and Constrained Costs with IDA Deployment Estimate 50% of Stated Requirement (Constant FY 1992 Dollars in Millions)

	Description of Alternative	Percent of Needs Met	Increase in Needs Met	Additive Costs[a]	Cost Per Percent of Added Needs Met
0	Baseline ACETEF	44%	0%	$60	NA
1	Provide 2.5 Shifts at ACETEF	72%	28%	$255	$9.1
2	Build LAC at Patuxent with 4-Shift Capacity	100%	56%	$448	$8.0
3	Build ECIT at Edwards (and Alt. 1 ACETEF)	100%	56%	$518	$9.3
4	Build LAC and ECIT (Alt. 2 + Alt.3)	100%	72%	$577	$10.3

[a] Uses IDA estimate with fiscally constrained F-22 deployment. Costs include future investments, 20-years of operations and deployments. Constant FY 1992 dollars are not discounted.

Table E-27. Needs and Constrained Costs with F-22 SPO Deployment Estimate 50% of Stated Requirement (Discounted FY 1992 Dollars in Millions)

	Description of Alternative	Percent of Needs Met	Increase in Needs Met	Additive Costs[a]	Cost Per Percent of Added Needs Met
0	Baseline ACETEF	44%	0%	$50	NA
1	Provide 2.5 Shifts at ACETEF	72%	28%	$277	$9.9
2	Build LAC at Patuxent with 4-Shift Capacity	100%	56%	$346	$6.2
3	Build ECIT at Edwards (and Alt. 1 ACETEF)	100%	56%	$278	$5.0
4	Build LAC and ECIT (Alt. 2 + Alt.3)	100%	56%	$323	$5.8

[a] Uses SPO estimate with fiscally unconstrained F-22 deployment. Costs include future investments, 20-years of operations and deployments. FY 1992 dollars are discounted at 10% per annum.

Table E-28. Needs and Constrained Costs with F-22 SPO Deployment Estimate 50% of Stated Requirement (Constant FY 1992 Dollars in Millions)

	Description of Alternative	Percent of Needs Met	Increase in Needs Met	Additive Costs[a]	Cost Per Percent of Added Needs Met
0	Baseline ACETEF	44%	0%	$60	NA
1	Provide 2.5 Shifts at ACETEF	72%	28%	$421	$15.0
2	Build LAC at Patuxent with 4-Shift Capacity	100%	56%	$614	$11.0
3	Build ECIT at Edwards (and Alt. 1 ACETEF)	100%	56%	$518	$9.3
4	Build LAC and ECIT (Alt. 2 + Alt.3)	100%	56%	$527	$10.3

[a] Uses SPO estimate with fiscally unconstrained F-22 deployment. Costs include future investments, 20-years of operations and deployments. Constant FY 1992 dollars are not discounted.

Table E-29. Needs and Constrained Costs with Minimum Deployment Estimate 50% of Stated Requirement (Discounted FY 1992 Dollars in Millions)

	Description of Alternative	Percent of Needs Met	Increase in Needs Met	Additive Costs[a]	Cost Per Percent of Added Needs Met
0	Baseline ACETEF	44%	0%	$50	NA
1	Provide 2.5 Shifts at ACETEF	72%	28%	$71	$2.5
2	Build LAC at Patuxent with 4-Shift Capacity	100%	56%	$159	$2.8
3	Build ECIT at Edwards (and Alt. 1 ACETEF)	100%	56%	$278	$5.0
4	Build LAC and ECIT (Alt. 2 + Alt.3)	100%	56%	$323	$5.8

[a] Uses minimum deployment estimate with F-22 deployed with no additional SIL or flight testing. Costs include future investments, 20-years of operations and deployments. FY 1992 dollars discounted at 10% per annum.

Table E-30. Needs and Constrained Costs with Minimum Deployment Estimate 50% of Stated Requirement (Constant FY 1992 Dollars in Millions)

	Description of Alternative	Percent of Needs Met	Increase in Needs Met	Additive Costs[a]	Cost Per Percent of Added Needs Met
0	Baseline ACETEF	44%	0%	$60	NA
1	Provide 2.5 Shifts at ACETEF	72%	28%	$125	$4.5
2	Build LAC at Patuxent with 4-Shift Capacity	100%	56%	$318	$5.7
3	Build ECIT at Edwards (and Alt. 1 ACETEF)	100%	56%	$518	$9.3
4	Build LAC and ECIT (Alt. 2 + Alt.3)	100%	56%	$577	$10.3

[a] Uses minimum deployment estimate with F-22 deployed with no additional SIL or flight testing. Costs include future investments, 20-years of operations and deployments. Constant FY 1992 dollars are not discounted.

Table E-31. Measures of Merit with IDA Deployment Estimate 50% of Stated Requirement (Discounted FY 1992 Dollars in Millions)

	Description of Alternative	Increase in Needs Met	Additive Costs[a]	Cost Per Percent of Added Needs Met	Unquantifiable	Total[b]
1	Provide 2.5 Shifts at ACETEF	4	1	4	4	13
2	Build LAC at Patuxent with 4-Shift Capacity	3	2	1	3	9
3	Build ECIT at Edwards (and Alt. 1 ACETEF)	2	3	2	2	9
4	Build LAC and ECIT (Alt. 2 + Alt.3)	1	4	4	1	10

[a] Uses IDA estimate with fiscally constrained F-22 deployment. Costs include future investments, 20-years of operations and deployments. FY 1992 dollars are discounted at 10% per annum.

[b] All categories equally weighted. Lowest score is best alternative.

Table E-32. Measures of Merit with IDA Deployment Estimate, 50% of Stated Requirement (Constant FY 1992 Dollars in Millions)

	Description of Alternative	Increase in Needs Met	Additive Costs[a]	Cost Per Percent of Added Needs Met	Unquantifiable	Total[b]
1	Provide 2.5 Shifts at ACETEF	4	1	2	4	11
2	Build LAC at Patuxent with 4-Shift Capacity	3	2	1	3	9
3	Build ECIT at Edwards (and Alt. 1 ACETEF)	2	3	3	2	10
4	Build LAC and ECIT (Alt. 2 + Alt.3)	1	4	4	1	10

[a] Uses IDA estimate with fiscally constrained F-22 deployment. Costs include future investments, 20-years of operations and deployments. Constant FY 1992 dollars are undiscounted.

[b] All categories equally weighted. Lowest score is best alternative.

Table E-33. Measures of Merit with F-22 SPO Deployment Estimate 50% of Stated Requirement (Discounted FY 1992 Dollars in Millions)

	Description of Alternative	Increase in Needs Met	Additive Costs[a]	Cost Per Percent of Added Needs Met	Unquantifiable	Total[b]
1	Provide 2.5 Shifts at ACETEF	4	1	4	4	13
2	Build LAC at Patuxent with 4-Shift Capacity	3	4	3	3	13
3	Build ECIT at Edwards (and Alt. 1 ACETEF)	2	2	1	2	7
4	Build LAC and ECIT (Alt. 2 + Alt.3)	1	3	2	1	7

[a] Uses SPO estimate with fiscally unconstrained F-22 deployment. Costs include future investments, 20-years of operations and deployments. FY 1992 dollars are discounted at 10% per annum.

[b] All categories equally weighted. Lowest score is best alternative.

Table E-34. Measures of Merit with F-22 SPO Deployment Estimate 50% of Stated Requirement (Constant FY 1992 Dollars in Millions)

	Description of Alternative	Increase in Needs Met	Additive Costs[a]	Cost Per Percent of Added Needs Met	Unquantifiable	Total[b]
1	Provide 2.5 Shifts at ACETEF	4	1	4	4	13
2	Build LAC at Patuxent with 4-Shift Capacity	3	4	3	3	13
3	Build ECIT at Edwards (and Alt. 1 ACETEF)	2	2	1	2	7
4	Build LAC and ECIT (Alt. 2 + Alt.3)	1	3	2	1	7

[a] Uses SPO estimate with fiscally unconstrained F-22 deployment. Costs include future investments, 20-years of operations and deployments. Constant FY 1992 dollars are not discounted.

[b] All categories equally weighted. Lowest score is best alternative.

Table E-35. Measures of Merit with Minimum Deployment Estimate 50% of Stated Requirement (Discounted FY 1992 Dollars in Millions)

	Description of Alternative	Increase in Needs Met	Additive Costs[a]	Cost Per Percent of Added Needs Met	Unquanti-fiable	Total[b]
1	Provide 2.5 Shifts at ACETEF	4	1	1	4	10
2	Build LAC at Patuxent with 4-Shift Capacity	3	2	2	3	10
3	Build ECIT at Edwards (and Alt. 1 ACETEF)	2	3	3	2	10
4	Build LAC and ECIT (Alt. 2 + Alt.3)	1	4	4	1	10

[a] Uses minimum deployment estimate with F-22 deployed with no additional SIL or flight testing. Costs include future investments, 20-years of operations and deployments. FY 1992 dollars discounted at 10% per annum.

[b] All categories equally weighted. Lowest score is best alternative.

Table E-36. Measures of Merit with Minimum Deployment Estimate 50% of Stated Requirement (Constant FY 1992 Dollars in Millions)

	Description of Alternative	Increase in Needs Met	Additive Costs[a]	Cost Per Percent of Added Needs Met	Unquanti-fiable	Total[b]
1	Provide 2.5 Shifts at ACETEF	4	1	1	4	10
2	Build LAC at Patuxent with 4-Shift Capacity	3	2	2	3	10
3	Build ECIT at Edwards (and Alt. 1 ACETEF)	2	3	3	2	10
4	Build LAC and ECIT (Alt. 2 + Alt.3)	1	4	4	1	10

[a] Uses minimum deployment estimate with F-22 deployed with no additional SIL or flight testing. Costs include future investments, 20-years of operations and deployments. Constant FY 1992 dollars are not discounted.

[b] All categories equally weighted. Lowest score is best alternative.

Table E-37. Needs and Constrained Costs with IDA Deployment Estimate 125% of Stated Requirement (Discounted FY 1992 Dollars in Millions)

	Description of Alternative	Percent of Needs Met	Increase in Needs Met	Additive Costs[a]	Cost Per Percent of Added Needs Met
0	Baseline ACETEF	18%	0%	$50	NA
1	Provide 2.5 Shifts at ACETEF	29%	11%	$167	$14.9
2	Build LAC at Patuxent with 4-Shift Capacity	46%	28%	$249	$8.9
3	Build ECIT at Edwards (and Alt. 1 ACETEF)	58%	40%	$264	$6.6
4	Build LAC and ECIT (Alt. 2 + Alt.3)	75%	58%	$323	$5.6

[a] Uses IDA estimate with fiscally constrained F-22 deployment. Costs include future investments, 20-years of operations and deployments. FY 1992 dollars are discounted at 10% per annum.

Table E-38. Needs and Constrained Costs with IDA Deployment Estimate 50% of Stated Requirement (Constant FY 1992 Dollars in Millions)

	Description of Alternative	Percent of Needs Met	Increase in Needs Met	Additive Costs[a]	Cost Per Percent of Added Needs Met
0	Baseline ACETEF	18%	0%	$60	NA
1	Provide 2.5 Shifts at ACETEF	29%	11%	$262	$23.4
2	Build LAC at Patuxent with 4-Shift Capacity	46%	28%	$454	$16.2
3	Build ECIT at Edwards (and Alt. 1 ACETEF)	58%	40%	$486	$12.2
4	Build LAC and ECIT (Alt. 2 + Alt.3)	75%	58%	$577	$10.0

[a] Uses IDA estimate with fiscally constrained F-22 deployment. Costs include future investments, 20-years of operations and deployments. Constant FY 1992 dollars are undiscounted.

Table E-39. Needs and Constrained Costs with F-22 SPO Deployment Estimate 125% of Stated Requirement (Discounted FY 1992 Dollars in Millions)

	Description of Alternative	Percent of Needs Met	Increase in Needs Met	Additive Costs[a]	Cost Per Percent of Added Needs Met
0	Baseline ACETEF	18%	0%	$50	NA
1	Provide 2.5 Shifts at ACETEF	29%	11%	$352	$25.1
2	Build LAC at Patuxent with 4-Shift Capacity	46%	28%	$264	$12.6
3	Build ECIT at Edwards (and Alt. 1 ACETEF)	58%	40%	$486	$6.6
4	Build LAC and ECIT (Alt. 2 + Alt.3)	75%	58%	$323	$5.6

[a] Uses IDA estimate with fiscally constrained F-22 deployment. Costs include future investments, 20-years of operations and deployments. FY 1992 dollars are discounted at 10% per annum.

Table E-40. Needs and Constrained Costs with F-22 SPO Deployment Estimate 125% of Stated Requirement (Constant FY 1992 Dollars in Millions)

	Description of Alternative	Percent of Needs Met	Increase in Needs Met	Additive Costs[a]	Cost Per Percent of Added Needs Met
0	Baseline ACETEF	18%	0%	$60	NA
1	Provide 2.5 Shifts at ACETEF	29%	11%	$428	$38.2
2	Build LAC at Patuxent with 4-Shift Capacity	46%	28%	$620	$22.1
3	Build ECIT at Edwards (and Alt. 1 ACETEF)	58%	40%	$486	$12.2
4	Build LAC and ECIT (Alt. 2 + Alt.3)	75%	58%	$577	$10.0

[a] Uses SPO estimate with fiscally unconstrained F-22 deployment. Costs include future investments, 20-years of operations and deployments. Constant FY 1992 dollars are not discounted.

Table E-41. Needs and Constrained Costs with Minimum Deployment Estimate 125% of Stated Requirement (Discounted FY 1992 Dollars in Millions)

	Description of Alternative	Percent of Needs Met	Increase in Needs Met	Additive Costs[a]	Cost Per Percent of Added Needs Met
0	Baseline ACETEF	18%	0%	$50	NA
1	Provide 2.5 Shifts at ACETEF	29%	11%	$75	$6.7
2	Build LAC at Patuxent with 4-Shift Capacity	46%	28%	$165	$5.9
3	Build ECIT at Edwards (and Alt. 1 ACETEF)	58%	40%	$264	$6.6
4	Build LAC and ECIT (Alt. 2 + Alt.3)	75%	58%	$323	$5.6

[a] Uses minimum deployment estimate with F-22 deployed with no additional SIL or flight testing. Costs include future investments, 20-years of operations and deployments. FY 1992 dollars discounted at 10% per annum.

Table E-42. Needs and Constrained Costs with Minimum Deployment Estimate 125% of Stated Requirement (Constant FY 1992 Dollars in Millions)

	Description of Alternative	Percent of Needs Met	Increase in Needs Met	Additive Costs[a]	Cost Per Percent of Added Needs Met
0	Baseline ACETEF	18%	0%	$60	NA
1	Provide 2.5 Shifts at ACETEF	29%	11%	$132	$11.8
2	Build LAC at Patuxent with 4-Shift Capacity	46%	28%	$324	$11.6
3	Build ECIT at Edwards (and Alt. 1 ACETEF)	58%	40%	$486	$12.2
4	Build LAC and ECIT (Alt. 2 + Alt.3)	75%	58%	$577	$10.0

[a] Uses minimum deployment estimate with F-22 deployed with no additional SIL or flight testing. Costs include future investments, 20-years of operations and deployments. FY 1992 constant dollars are not discounted.

Table E-43. Measures of Merit with IDA Deployment Estimate 125% of Stated Requirement, (Discounted FY 1992 Dollars in Millions)

	Description of Alternative	Increase in Needs Met	Additive Costs[a]	Cost Per Percent of Added Needs Met	Unquantifiable	Total[b]
1	Provide 2.5 Shifts at ACETEF	4	1	4	4	13
2	Build LAC at Patuxent with 4-Shift Capacity	3	2	3	3	11
3	Build ECIT at Edwards (and Alt. 1 ACETEF)	2	3	2	2	9
4	Build LAC and ECIT (Alt. 2 + Alt.3)	1	4	1	1	7

[a] Uses IDA estimate with fiscally constrained F-22 deployment. Costs include future investments, 20-years of operations and deployments. FY 1992 dollars are discounted at 10% per annum.

[b] All categories equally weighted. Lowest score is best alternative.

Table E-44. Measures of Merit with IDA Deployment Estimate 125% of Stated Requirement, (Constant FY 1992 Dollars in Millions)

	Description of Alternative	Increase in Needs Met	Additive Costs[a]	Cost Per Percent of Added Needs Met	Unquantifiable	Total[b]
1	Provide 2.5 Shifts at ACETEF	4	1	4	4	13
2	Build LAC at Patuxent with 4-Shift Capacity	3	2	3	3	11
3	Build ECIT at Edwards (and Alt. 1 ACETEF)	2	3	2	2	9
4	Build LAC and ECIT (Alt. 2 + Alt.3)	1	4	1	1	7

[a] Uses IDA estimate with fiscally constrained F-22 deployment. Costs include future investments, 20-years of operations and deployments. Constant FY 1992 dollars are undiscounted.

[b] All categories equally weighted. Lowest score is best alternative.

Table E-45. Measures of Merit with F-22 SPO Deployment Estimate 125% of Stated Requirement, (Discounted FY 1992 Dollars in Millions)

	Description of Alternative	Increase in Needs Met	Additive Costs[a]	Cost Per Percent of Added Needs Met	Unquantifiable	Total[b]
1	Provide 2.5 Shifts at ACETEF	4	2	4	4	14
2	Build LAC at Patuxent with 4-Shift Capacity	3	4	3	3	13
3	Build ECIT at Edwards (and Alt. 1 ACETEF)	2	1	2	2	7
4	Build LAC and ECIT (Alt. 2 + Alt.3)	1	3	1	1	6

[a] Uses IDA estimate with fiscally constrained F-22 deployment. Costs include future investments, 20-years of operations and deployments. FY 1992 dollars are discounted at 10% per annum.

[b] All categories equally weighted. Lowest score is best alternative.

Table E-46. Measures of Merit with F-22 SPO Deployment Estimate 125% of Stated Requirement, (Constant FY 1992 Dollars in Millions)

	Description of Alternative	Increase in Needs Met	Additive Costs[a]	Cost Per Percent of Added Needs Met	Unquantifiable	Total[b]
1	Provide 2.5 Shifts at ACETEF	4	1	4	4	13
2	Build LAC at Patuxent with 4-Shift Capacity	3	4	3	3	13
3	Build ECIT at Edwards (and Alt. 1 ACETEF)	2	2	2	2	8
4	Build LAC and ECIT (Alt. 2 + Alt.3)	1	3	1	1	6

[a] Uses IDA estimate with fiscally constrained F-22 deployment. Costs include future investments, 20-years of operations and deployments. Constant FY 1992 dollars are undiscounted.

[b] All categories equally weighted. Lowest score is best alternative.

Table E-47. Measures of Merit with Minimum Deployment Estimate 125% of Stated Requirement, (Discounted FY 1992 Dollars in Millions)

	Description of Alternative	Increase in Needs Met	Additive Costs[a]	Cost Per Percent of Added Needs Met	Unquanti-fiable	Total[b]
1	Provide 2.5 Shifts at ACETEF	4	1	4	4	13
2	Build LAC at Patuxent with 4-Shift Capacity	3	2	2	3	10
3	Build ECIT at Edwards (and Alt. 1 ACETEF)	2	3	3	2	10
4	Build LAC and ECIT (Alt. 2 + Alt.3)	1	4	1	1	7

[a] Uses minimum deployment estimate with F-22 deployed with no Costs additional SIL or flight testing. Costs include future investments, 20-years of operations and deployments. FY 1992 dollars discounted at 10% per annum.

[b] All categories equally weighted. Lowest score is best alternative.

Table E-48. Measures of Merit with Minimum Deployment Estimate 125% of Stated Requirement, (Constant FY 1992 Dollars in Millions)s)

	Description of Alternative	Increase in Needs Met	Additive Costs[a]	Cost Per Percent of Added Needs Met	Unquanti-fiable	Total[b]
1	Provide 2.5 Shifts at ACETEF	4	1	3	4	12
2	Build LAC at Patuxent with 4-Shift Capacity	3	2	2	3	10
3	Build ECIT at Edwards (and Alt. 1 ACETEF)	2	3	4	2	11
4	Build LAC and ECIT (Alt. 2 + Alt.3)	1	4	1	1	7

[a] Uses minimum deployment estimate with F-22 deployed with no Costs additional SIL or flight testing. Costs include future investments, 20-years of operations and deployments. Constant FY 1992 dollars are undiscounted.

[b] All categories equally weighted. Lowest score is best alternative.

Table E-49. Needs and Constrained Costs with IDA Deployment Estimate 150% of Stated Requirement (Discounted FY 1992 Dollars in Millions)

	Description of Alternative	Percent of Needs Met	Increase in Needs Met	Additive Costs[a]	Cost Per Percent of Added Needs Met
0	Baseline ACETEF	15%	0%	$50	NA
1	Provide 2.5 Shifts at ACETEF	24%	9%	$167	$17.9
2	Build LAC at Patuxent with 4-Shift Capacity	38%	23%	$249	$10.7
3	Build ECIT at Edwards (and Alt. 1 ACETEF)	48%	33%	$264	$7.9
4	Build LAC and ECIT (Alt. 2 + Alt.3)	63%	48%	$323	$6.7

[a] Uses IDA estimate with fiscally constrained F-22 deployment. Costs include future investments, 20-years of operations and deployments. FY 1992 dollars are discounted at 10% per annum.

Table E-50. Needs and Constrained Costs with IDA Deployment Estimate 150% of Stated Requirement (Constant FY 1992 Dollars in Millions)

	Description of Alternative	Percent of Needs Met	Increase in Needs Met	Additive Costs[a]	Cost Per Percent of Added Needs Met
0	Baseline ACETEF	15%	0%	$60	NA
1	Provide 2.5 Shifts at ACETEF	24%	9%	$262	$28.1
2	Build LAC at Patuxent with 4-Shift Capacity	38%	23%	$454	$19.5
3	Build ECIT at Edwards (and Alt. 1 ACETEF)	48%	33%	$486	$14.6
4	Build LAC and ECIT (Alt. 2 + Alt.3)	63%	48%	$577	$12.0

[a] Uses IDA estimate with fiscally constrained F-22 deployment. Costs include future investments, 20-years of operations and deployments. FY 1992 constant dollars are not discounted.

Table E-51. Needs and Constrained Costs with F-22 SPO Deployment Estimate 150% of Stated Requirement (Discounted FY 1992 Dollars in Millions)

	Description of Alternative	Percent of Needs Met	Increase in Needs Met	Additive Costs[a]	Cost Per Percent of Added Needs Met
0	Baseline ACETEF	15%	0%	$50	NA
1	Provide 2.5 Shifts at ACETEF	24%	9%	$281	$30.1
2	Build LAC at Patuxent with 4-Shift Capacity	38%	23%	$352	$15.1
3	Build ECIT at Edwards (and Alt. 1 ACETEF)	48%	33%	$264	$7.9
4	Build LAC and ECIT (Alt. 2 + Alt.3)	63%	48%	$323	$6.7

[a] Uses SPO estimate with fiscaly unconstrained F-22 deployment. Costs include future investments, 20-years of operations and deployments. FY 1992 dollars are discounted at 10% per annum.

Table E-52. Needs and Constrained Costs with F-22 SPO Deployment Estimate 150% of Stated Requirement (Constant FY 1992 Dollars in Millions)

	Description of Alternative	Percent of Needs Met	Increase in Needs Met	Additive Costs[a]	Cost Per Percent of Added Needs Met
0	Baseline ACETEF	15%	0%	$60	NA
1	Provide 2.5 Shifts at ACETEF	24%	9%	$428	$45.9
2	Build LAC at Patuxent with 4-Shift Capacity	38%	23%	$620	$26.6
3	Build ECIT at Edwards (and Alt. 1 ACETEF)	48%	33%	$486	$14.6
4	Build LAC and ECIT (Alt. 2 + Alt.3)	63%	48%	$577	$12.0

[a] Uses SPO estimate with fiscally unconstrained F-22 deployment. Costs include future investments, 20-years of operations and deployments. FY 1992 constant dollars are not discounted.

Table E-53. Needs and Constrained Costs with Minimum Deployment Estimate 150% of Stated Requirement (Discounted FY 1992 Dollars in Millions)

	Description of Alternative	Percent of Needs Met	Increase in Needs Met	Additive Costs[a]	Cost Per Percent of Added Needs Met
0	Baseline ACETEF	15%	0%	$50	NA
1	Provide 2.5 Shifts at ACETEF	24%	9%	$75	$8.0
2	Build LAC at Patuxent with 4-Shift Capacity	38%	23%	$165	$7.1
3	Build ECIT at Edwards (and Alt. 1 ACETEF)	48%	33%	$264	$7.9
4	Build LAC and ECIT (Alt. 2 + Alt.3)	63%	48%	$323	$6.7

[a] Uses minimum deployment estimate with F-22 deployed with no additional SIL or flight testing. Costs include future investments, 20-years of operations and deployments. FY 1992 dollars discounted at 10% per annum.

Table E-54. Needs and Constrained Costs with Minimum Deployment Estimate 150% of Stated Requirement (Constant FY 1992 Dollars in Millions)

	Description of Alternative	Percent of Needs Met	Increase in Needs Met	Additive Costs[a]	Cost Per Percent of Added Needs Met
0	Baseline ACETEF	15%	0%	$60	NA
1	Provide 2.5 Shifts at ACETEF	24%	9%	$132	$14.1
2	Build LAC at Patuxent with 4-Shift Capacity	38%	23%	$324	$13.9
3	Build ECIT at Edwards (and Alt. 1 ACETEF)	48%	33%	$486	$14.6
4	Build LAC and ECIT (Alt. 2 + Alt.3)	63%	48%	$589	$12.0

[a] Uses minimum deployment estimate with F-22 deployed with no additional SIL or flight testing. Costs include future investments, 20-years of operations and deployments. FY 1992 constant dollars are not discounted.

Table E-55. Measures of Merit with IDA Deployment Estimate 150% of Stated Requirement, (Discounted FY 1992 Dollars in Millions)

	Description of Alternative	Increase in Needs Met	Additive Costs[a]	Cost Per Percent of Added Needs Met	Unquanti-fiable	Total[b]
1	Provide 2.5 Shifts at ACETEF	4	1	4	4	13
2	Build LAC at Patuxent with 4-Shift Capacity	3	2	3	3	11
3	Build ECIT at Edwards (and Alt. 1 ACETEF)	2	3	2	2	9
4	Build LAC and ECIT (Alt. 2 + Alt.3)	1	4	1	1	7

[a] Uses IDA estimate with fiscally constrained F-22 deployment. Costs include future investments, 20years of operations and deployments. FY 1992 dollars are discounted at 10% per annum.

[b] All categories equally weighted. Lowest score is best alternative.

Table E-56. Measures of Merit with IDA Deployment Estimate 150% of Stated Requirement, (Constant FY 1992 Dollars in Millions)

	Description of Alternative	Increase in Needs Met	Additive Costs[a]	Cost Per Percent of Added Needs Met	Unquanti-fiable	Total[b]
1	Provide 2.5 Shifts at ACETEF	4	1	4	4	13
2	Build LAC at Patuxent with 4-Shift Capacity	3	2	3	3	11
3	Build ECIT at Edwards (and Alt. 1 ACETEF)	2	3	2	2	9
4	Build LAC and ECIT (Alt. 2 + Alt.3)	1	4	1	1	7

[a] Uses IDA estimate with fiscally constrained F-22 deployment. Costs include future investments, 20years of operations and deployments. FY 1992 constant dollars are not discounted.

[b] All categories equally weighted. Lowest score is best alternative.

Table E-57. Measures of Merit with F-22 SPO Deployment Estimate 150% of Stated Requirement (Discounted FY 1992 Dollars in Millions)

	Description of Alternative	Increase in Needs Met	Additive Costs[a]	Cost Per Percent of Added Needs Met	Unquanti-fiable	Total[b]
1	Provide 2.5 Shifts at ACETEF	4	2	4	4	14
2	Build LAC at Patuxent with 4-Shift Capacity	3	4	3	3	13
3	Build ECIT at Edwards (and Alt. 1 ACETEF)	2	1	2	2	7
4	Build LAC and ECIT (Alt. 2 + Alt.3)	1	3	1	1	6

[a] Uses SPO estimate with fiscally uncontrained F-22 deplyment. Costs include future investments, 20-years of operations and deployments. FY 1992 dollars are discounted at 10% per annum.

[b] All categories equally weighted. Lowest score is best alternative.

Table E-58. Measures of Merit with F-22 SPO Deployment Estimate 150% of Stated Requirement (Constant FY 1992 Dollars in Millions)

	Description of Alternative	Increase in Needs Met	Additive Costs[a]	Cost Per Percent of Added Needs Met	Unquanti-fiable	Total[b]
1	Provide 2.5 Shifts at ACETEF	4	1	4	4	13
2	Build LAC at Patuxent with 4-Shift Capacity	3	4	3	3	13
3	Build ECIT at Edwards (and Alt. 1 ACETEF)	2	2	2	2	8
4	Build LAC and ECIT (Alt. 2 + Alt.3)	1	3	1	1	6

[a] Uses SPO estimate with fiscally uncontrained F-22 deplyment. Costs include future investments, 20-years of operations and deployments. Constant FY 1992 dollars are not discounted.

[b] All categories equally weighted. Lowest score is best alternative.

Table E-59. Measures of Merit with Minimum Deployment Estimate 150% of Stated Requirement (Discounted FY 1992 Dollars in Millions)

	Description of Alternative	Increase in Needs Met	Additive Costs[a]	Cost Per Percent of Added Needs Met	Unquanti-fiable	Total[b]
1	Provide 2.5 Shifts at ACETEF	4	1	4	4	13
2	Build LAC at Patuxent with 4-Shift Capacity	3	2	2	3	10
3	Build ECIT at Edwards (and Alt. 1 ACETEF)	2	3	3	2	10
4	Build LAC and ECIT (Alt. 2 + Alt.3)	1	4	1	1	7

[a] Uses minimum deployment estimate with F-22 deployed with no additional SIL or flight testing. Costs include future investments, 20-years of operations and deployments. FY 1992 dollars discounted at 10% per annum.

[b] All categories equally weighted. Lowest score is best alternative.

Table E-60. Measures of Merit with Minimum Deployment Estimate 150% of Stated Requirement (Constant FY 1992 Dollars in Millions)

	Description of Alternative	Increase in Needs Met	Additive Costs[a]	Cost Per Percent of Added Needs Met	Unquanti-fiable	Total[b]
1	Provide 2.5 Shifts at ACETEF	4	1	3	4	12
2	Build LAC at Patuxent with 4-Shift Capacity	3	2	2	3	10
3	Build ECIT at Edwards (and Alt. 1 ACETEF)	2	3	4	2	11
4	Build LAC and ECIT (Alt. 2 + Alt.3)	1	4	1	1	7

[a] Uses minimum deployment estimate with F-22 deployed with no additional SIL or flight testing. Costs include future investments, 20-years of operations and deployments. FY 1992 constant dollars are not discounted.

[b] All categories equally weighted. Lowest score is best alternative.

Table E-61. Preferred Alternatives

	Best, Next Best Alternative				
	50%	75%	100%	125%	150%
With IDA Estimate, Discounted $					
Dollars/Requirement	2, 3	3, 4	4, 3	4, 3	4, 3
Total	2/3	3/4	4, 3	4, 3	4, 3
With IDA Estimate, Constant $					
Dollars/Requirement	2, 1	3, 4	4, 3	4, 3	4, 3
Total	2/3	3/4	4, 3	4, 3	4, 3
With F-22 Estimate, Discounted $					
Dollars/Requirement	3, 4	3, 4	4, 3	4, 3	4, 3
Total	3/4	3, 4	4, 3	4, 3	4, 3
With F-22 Estimate, Constant $					
Dollars/Requirement	3, 4	3, 4	4, 3	4, 3	4, 3
Total	3/4	3/4	4, 3	4, 3	4, 3
With Minimum Estimate, Discounted $					
Dollars/Requirement	1, 2	2, 1	4, 2	4, 2	4, 2
Total	1/2/3/4	2, 3/4	4, 2/3	4, 2/3	4, 2/3
With Minimum Estimate, Constant $					
Dollars/Requirement	1, 2	2, 1	4, 2	4, 2	4, 2
Total	1/2/3/4	2, 3/4	4, 2	4, 2	4, 2

Notes: A diagonal (/) designates a tie. Alternative 1, provide 2.5 shifts at ACETEF; Alternative 2, build LAC at Patuxent with 4-shift capacity; Alternative 3, build ECIT at Edwards (and Alternative 1 ACETEF); and Alternative 4, build LAC and ECIT (Alternative 2 + Alternative 3).

APPENDIX F

SERVICE COVER LETTERS

APPENDIX F

SERVICE COVER LETTERS

This appendix contains copies of Navy and Air Force cover letters regarding ACETEF issues and F-22 deployment costs, respectively. The Navy letter stresses the advantages of ACETEF, and the Air Force letter provides a rationale for the high cost of deploying the F-22 to ACETEF for electronic combat/avionics ground testing.

DEPARTMENT OF THE NAVY
NAVAL AIR SYSTEMS COMMAND
NAVAL AIR SYSTEMS COMMAND HEADQUARTERS
WASHINGTON, DC 20361

IN REPLY REFER TO

3900
Ser NAWC-22B/018
30 January 1992

FIRST ENDORSEMENT on Naval Air Warfare Center Aircraft Division ltr 3900 Ser SY02C/032 of 13 Jan 92

From: Commander, Naval Air Warfare Center
To: Deputy Director of Defense, Research and Engineering (Test and Evaluation), Office of the Secretary of Defense, Deputy Under the Secretary of Test and Evaluation, Pentagon, Washington, D.C. 20301
Via: Chief of Naval Operations (OP-913)

Subj: AIR COMBAT ENVIRONMENT TEST AND EVALUATION FACILITY (ACETEF)/ELECTRONIC COMBAT INTEGRATED TEST (ECIT) STUDY COMMENTS

1. The subject letter has been reviewed. I agree with both the rationale and the conclusions in the letter and its supporting documentation. The consolidation of aircraft and aircraft systems research and development functions from NAWCAD Warminster to NAWCAD Patuxent provides the opportunity in the future to expand the use of ACETEF to include applied research and early development tasks. The facility will become even more of a unique national asset. This package is forwarded with my strongest recommendation that the Air Combat Environment Test and Evaluation Facility (ACETEF) be designated as the primary DoD Integrated Systems Test Facility.

2. As the chartered agent of Commander, Naval Air Systems Command (COMNAVAIRSYSCOM) for test and evaluation facilities and execution, this endorsement constitutes endorsement by COMNAVAIRSYSCOM. My point of contact is Mr. Tom Metz at DSN 286-7730 or commercial (703) 746-7730.

G. H. STROHSAHL

Copy to:
NAWCAD, Patuxent River, MD (SY04, SY02C)
COMNAVAIRSYSCOM, Washington DC (AIR-00, 05)

DEPARTMENT OF THE NAVY

NAVAL AIR WARFARE CENTER
AIRCRAFT DIVISION
PATUXENT RIVER, MARYLAND 20670-5304

3900
Ser SY02C/032

[illegible] 17 1992

From: Commander, Naval Air Warfare Center Aircraft Division, Patuxent River, Maryland 20670-5304

To: Deputy Director of Defense, Research and Engineering (Test and Evaluation), Office of the Secretary of Defense, Deputy Under the Secretary of Test and Evaluation, Pentagon, Washington, D.C. 20301

Via: (1) Commander, Naval Air Warfare Center Headquarters (NAVAIRWARCEN-22), Washington, D.C. 20361-6000
(2) Chief of Naval Operations (OP-913), Navy Department, Washington, D.C. 20350-2000

Subj: AIR COMBAT ENVIRONMENT TEST AND EVALUATION FACILITY (ACETEF)/ELECTRONIC COMBAT INTEGRATED TEST (ECIT) STUDY COMMENTS

Ref: (a) Draft Memorandum for Chief of Naval Operations OP-91 from DDDR&E(T&E) titled Cost Comparison of ECIT and ACETEF
(b) ACETEF Program Management Plan of 15 April 1991

Encl: (1) Supporting Information for Institute for Defense Analysis Study of ACETEF/Large Anechoic Chamber and ECIT

1. Congress directed the Office of the Secretary of Defense to compare the costs of developing the ECIT or modifying the ACETEF to support Air Force programs. Department of Defense Deputy for Research and Engineering (Test and Evaluation) (DDDR&E(T&E)) is conducting the study. The following information, as requested in reference (a), is provided for this study.

2. ACETEF is recognized as a national asset and is the world's leader and only existing (programmed) category I installed systems test facility (ISTF) existing for DT and OT testing of full aircraft systems. ACETEF with its existing Hardware-in-the-loop (HIL), man-in-the-loop (MIL), friendly (blue), potential enemy (red) and commercial/third world (gray) electronic combat radiations, targets and systems stimulators is several years ahead of the ECIT development and expertise. Given today's environment, (i.e., rapidly declining DOD budgets, the recognition of the Navy's capability by the emerging Project Reliance report which recognizes the Navy as lead on ISTF's,

plus a potentially declining workload), it is logical to conclude that it is most prudent to concentrate efforts on ACETEF.

3. The ACETEF is capable and has already supported several Air Force DT and OT programs such as the F-15E, F-16, and EC-130 aircraft. Programs such as the F-22 can be accommodated in the existing ACETEF anechoic chamber and the B-1 and B-2 in the shielded hangar (with test limitations) until the new anechoic chamber is built. To meet this increased workload, multiple shift operations and the concept of operations as described in paragraph 5 below are expected to be used and have proven to be highly successful. The Navy and its ACETEF are ready to assume this added role should DOD direct.

4. The general requirement of an ACETEF type test facility lies in six areas: test realism, advanced threat, security, systems integration, interoperability, and cost. Both DT and OT testing must be conducted under a variety of conditions that represent conditions in the "real world" that include the appropriate numbers, types and proper performance of threat, neutral and friendly systems. Both HIL and MIL systems under test and threat systems are required to assess the full systems performance including the man-machine interface. This along with the number of special access programs drive the need to perform testing in a secure test environment. The major factor in the need for ACETEF type testing is in the areas of integration and interoperability. These drive both the fidelity and scope of system and stimulation to weapons systems or multiple weapons systems in the latter case. Much of the fidelity and simultaneous stimulation cannot be performed in flight. Finally, all of the previous factors drive the cost of testing in free space to a prohibitive level, without the use of facilities like ACETEF that testing would not be able to be performed. Enclosure (1) provides specific examples of Navy and Air Force Test requirements.

5. The concept of operations for ACETEF support of Air Force programs has been and will be that the Air Force has the role of test conductor while the Navy hosts and provides as needed the test resource support along with engineering support if needed. It is expected that a program F-22 would use the ACETEF for an 8 to 12 week period supported by the Air Force test team, system contractors etc., conduct the tests with Navy support, and correct problems that can be corrected on site. Other hardware and software corrective actions identified in the ACETEF will occur at the prime contractor/government development site with the data collected from the ACETEF. Usually, programs return to the ACETEF for tests after correc-

Subj: AIR COMBAT ENVIRONMENT TEST AND EVALUATION FACILITY (ACETEF)/ELECTRONIC COMBAT INTEGRATED TEST (ECIT) STUDY COMMENTS

tive actions have been taken. Examples include: F-15, F-16, EC-130 COMPASS CALL, F/A-18, F-14D, HH-60, AH-64, etc.

6. Enclosure (1) provides answers to the specific questions directed to the Navy. The ability of the ACETEF to carry out the testing as stated in the Senate Appropriations Committee intent is dependent on the funding level provided in reference (b) and $60M to $70M funding for the large anechoic chamber.

7. Our point of contact is Mr. Dan Macone at DSN 326-6309 or commercial 301-737-6309.

R. PARKINSON
By direction

DEPARTMENT OF THE AIR FORCE
HEADQUARTERS UNITED STATES AIR FORCE
WASHINGTON DC

17 APR 1992

MEMORANDUM FOR DEPUTY DIRECTOR DEFENSE RESEARCH AND ENGINEERING (TEST AND EVALUATION)

SUBJECT: Details Supporting F-22 "Differential Cost Estimate Rationale," ECIT/ACETEF Comparison - INFORMATION MEMORANDUM

The referenced memorandum requested additional data in support of the IDA-led ECIT/ACETEF Comparison study. The requested breakout of F-22 SPO estimated costs for ACETEF testing is attached. The plan you asked for describing infrastructure capabilities necessary to support F-22 avionics testing is the F-22 Avionics Test Concept (ATC) document. This internal program office document was previously provided to the OSD staff as a reference in support of the F-22 SPO's 6 Jan 92 TEMP submission.

The F-22 avionics system represents one of the most challenging Engineering and Manufacturing Development test and evaluation efforts yet undertaken by the DoD. The very nature of the F-22 design requires a detailed, rigorous, incremental development test process and a uniquely configured test infrastructure capable of supporting that process. A collocated installed system test facility is an essential tool for supporting developmental flight test of the F-22 or any aircraft with highly integrated avionics. We believe the F-22 test strategy represents the optimum application of DoD test facilities and the most cost effective approach for supporting its program milestone decisions.

Requiring the F-22 to test at Patuxent River NAS would significantly disrupt the F-22 test program. It would add at least $350 million to the program cost, up to 8 additional months of development test, and perhaps most importantly add additional technical and programmatic risk. In order to maintain acceptable development confidence levels, the SPO would have to substantially replan, redirect, and duplicate test assets, test expertise, and test personnel. The F-22 SPO would have to deploy and operate the test aircraft at the ACETEF complex, develop and maintain two SILs, pre-position additional aircraft spares, and duplicate both operational and support personnel. Technically, the change would require the SPO to rely more on contractor development testing and increase the likelihood of a "fly-fix-fly" open air development test.

Also, while the ACETEF staff has a "can-do" attitude, they haven't yet formally committed to supporting the F-22 and I can't help but be concerned that

the SPO won't be fully supported when they bring their requirement for 26 months of dedicated "chamber time" (over a 4-year period) to the facility manager. I am convinced that we are getting the relationship between program and test infrastructure reversed. Adding technical and programmatic risk to a multibillion-dollar program's test and evaluation strategy in order to accommodate a desire to consolidate two facility upgrade projects is fundamentally wrong. I can see no discernable value added to the mission by barring ECIT upgrades.

I urge you and your staff to support the reinstatement of funds for the ECIT program.. We really must have the appropriate tools to conduct disciplined testing. The DoD doesn't need another B-1B test and evaluation experience. Please let me know if there is anything else you need in developing your response to the Congress.

HOWARD W. LEAF, Lt Gen, USAF (Ret)
Director, Test and Evaluation

1 Atch
F-22 System Program Office Cost
Estimate at the ACETEF, Mar 92.

F-22 SYSTEM PROGRAM OFFICE COST ESTIMATE FOR THE DUPLICATION OF REQUIRED TEST ASSETS AT THE AIR COMBAT ENVIRONMENT TEST AND EVALUATION FACILITY

1. The following cost estimates and associated assumptions are provided in response to the inquiry of the major program costs associated with having a geographically separated test facility at the Air Combat Environment Test and Evaluation Facility (ACETEF). These costs are in addition to the already programmed costs of establishing the required test capabilities at the F-22 primary test site, the Air Force Flight Test Center (AFFTC). The total costs of establishing the additional test capability at the ACETEF complex are summarized by fiscal year in Table 1. The additional costs fall into three basic categories which are the establishment of a Systems Integration Laboratory (SIL) at the ACETEF complex, the deployment of a flight test aircraft to ACETEF for an extended period, and the operation and support of the SIL and the aircraft while at the ACETEF complex. The breakdown of each of these cost categories are discussed in subsequent paragraphs.

FY92	FY93	FY94	FY95	FY96
22.4	48.6	44.0	20.5	21.2
FY97	**FY98**	**FY99**	**FY00**	**TOTAL**
21.9	85.0	88.0	6.0	357.6

Table 1. Summary of Costs (TY $ in millions)

2. The following assumptions and cost breakdown is in support of establishing a Systems Integration Laboratory (SIL) and a basic avionics test and anomaly investigation capability at the ACETEF complex. The initial assumption is that facility space of 15,000 square feet is available to the F-22 program at the ACETEF complex with sufficient power and cooling and open-air range access to support the SIL operating requirements. Should basic facility upgrades be required to meet these requirements, their costs are not considered in this estimate. The costs for establishing the SIL are broken down into two categories. Category 1 which includes the costs of basic facility setup, support equipment, and instrumentation, and Category 2 which includes the population of the facility with actual F-22 avionics hardware and associated spares. These costs are detailed by fiscal year in Table 2.

	FY92	FY93	FY94	TOTAL
Category 1		12.7	13.0	25.7
Category 2	22.4	35.9	31.0	89.3
SIL Total				115.0

Table 2. System Integration Laboratory Costs (TY $ in millions)

3. The following assumptions and cost breakdown are in support of deploying an avionics flight test aircraft to the ACETEF facility for avionics ground and chamber testing. This requires additional aircraft spares to be positioned at Patuxent River Naval Air Station (NAS), as well as, the duplication of operation and support personnel for the maintenance and support of the aircraft. The schedule of airborne avionics test at the primary test location would be impacted by the lost test asset while it is deployed. During the absence of the test asset, it is assumed that other avionics test assets would make up some of the lost flights, but no recoupment of the test time was considered due to the risk involved in that assumption. The lost test time amounts to 26 months of aircraft availability during the avionics flight test development phase. This lost time would be reaccomplished in FY98 and FY99 and a 25% allowance for regression and duplication test is assumed for test center-to-test center correlation. The cost estimates assume 20 aircraft flying hours per month and the costs are calculated based on labor hours assuming 1,750 labor hours per flight test hour at $70 per hour. These costs are detailed by fiscal year in Table 3.

	FY98	FY99	TOTAL
Aircraft Flight Test Costs	62.5	64.7	127.2

Table 3. Aircraft Flight Test Costs (TY $ in millions)

4. The following assumptions and cost breakdown are in support of the operation of the SIL at the ACETEF complex. The SIL requires 100 contractor personnel for the basic facility operation and test and evaluation tasks. Based on the reduced scope of effort to be accomplished at the ACETEF complex, only 75% or 75 personnel will be required. The facility will be operating for 63 months at 160 hours a month during fiscal years FY95 through FY00. The basic pay rate is assumed to be $100 per hour in BY90$ which calculates to $1.2 M per month. These costs are then converted to TY$ and are detailed in Table 4.

	FY95	FY96	FY97	FY98	FY99	FY00	TOTAL
SIL Operating Costs	20.5	21.2	21.9	22.5	23.3	6.0	115.4

Table 4. SIL Operating Costs (TY $ in millions)

APPENDIX G

ADDITIONAL ISSUES

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UNIQUE CAPABILITIES OF INSTALLED SYSTEMS TEST FACILITIES

This section summarizes some of the key points made by the Navy based on their ACETEF experience.

The most "up to date" hardware and software configuration available for engineering test is the hardware and software that is physically installed in an aircraft. The "spread bench" configuration often is different. The "SIL" is used principally by the contractor to physically integrate the system—not to support ISTF or flight test.

The Navy views such integration facilities as the SIL as being suited for tests where one wants to get "in the box." Hardware-in-the-loop (HITL) facilities are used for testing "between the boxes." ISTFs are used for testing of system-level responses. (Note that the IFAST falls more within the Reliance definition of hardware-in-the-loop than integration facility.)

The Navy outlined five classes of testing where an ISTF provides the ability to do something not possible in an integration facility:

- Tests that require a level of stimulation greater than that likely to be found in other less capable facilities such as SILs and HITL facilities.
- Tests that require the test article to be "installed" in order to properly evaluate the potential effects of the airframe on system performance.
- Tests that require the system's radiating elements to operate in an "in flight" configuration.
- Tempest tests of specific hardware installations (as opposed to designs).
- Tests that require absolute security of RF signals, either threat or friendly.

Examples for these classes of tests are described in the paragraphs that follow.

Case 1—Tests requiring a higher level of stimulation capability than is likely to be available at other than ISTF facilities. A specific example is the test of the ALQ-149 Communication Intercept Receiver for the EA-6B AVCAP program. The system

had been bench tested successfully by the manufacturer, and had passed its Acceptance Test Procedures in an HWIL facility at PMTC over a 3- to 6-month test program. The first aircraft with an installed system then went to the ACETEF for testing. During the first week of testing in the chamber, the system failed when subjected to a dense communication environment. (Buffers internal to the system became saturated, and the processor locked up.) In theory, had the HWIL facility at PMTC been adequately facilitated with high-density stimulators, this problem could have been found there.

However, because each program tends to have (and need) its own SIL and HWIL, such an investment would need to be repeated at every SIL and HWIL in the Navy. This is not the Navy's approach. Rather, the Navy has concentrated capability at ACETEF. It is not the anechoic chamber, per se, or even the concept of an ISTF, that solves the Case I type problem, as much as it is a strategy that creates a limited number of high-value facilities, by putting the high-capability simulators and stimulators at an ISTF.

Case 2—Tests wherein the interaction of the airframe and the test article, in a radiating environment, are of interest. The High Speed Anti-radiation Missile (HARM) is carried on the E/A-6 aircraft. Testing in the ACETEF revealed a directional problem—the threat signal *reflected* off the A-6 airframe into the seeker of the HARM. This caused threats that were up to 90 degrees off the nose to appear to be on the nose. This problem could only be identified in a facility that permits the test article to be "installed" and the threat to be radiating. A SIL and HWIL would not (and did not) identify this class of problem. The ACETEF identified it quickly.

Case 3—Tests requiring that the system be radiating in an "in flight" fashion. The F-14D program involved integration of a GFE Electronic Warfare system in the airplane. The system consisted of the ALR-67 Radar Warning Receiver (RWR), the ALQ-165 Airborne Self Protection Jammer (ASPJ), and the ALE-39 Chaff Dispenser. The aircraft itself was equipped with the APF-7 Attack Radar. The system was tested in the contractor's ISL and determined to be operating correctly. NAVAIR directed that additional testing be performed by Grumman at ACETEF. NATC provided the facility, "the electrons," and general oversight for safety and reasonableness of test methodology. The contractor conducted the test, which ran from 1 January through 31 March 1990. The testing revealed 22 major problems, 17 of which were fixed during the period of the test. Basically, by testing in a facility that put all the subsystems into their installed configuration, while radiating, and in a threat environment, the Navy was able to demonstrate that the attack radar was jammed by the ASPJ, and that numerous other "software timing" problems existed. These problems were not apparent in the spread

bench layout and geometry of the SIL, where radiating elements were not operating in a normal, "installed" fashion. These sorts of tests require an ISTF.

Case 4—Tempest tests that evaluate the adequacy of specific installations. Certain Navy systems have highly classified data available within the aircraft in a variety of frequencies. Although the inherent design of such systems theoretically prevents inadvertent emission of such data, the actual manufacturing and assembly process may not afford the design-level protection. Testing an aircraft in an ISTF can provide reasonable assurance that the aircraft in fact protects the classified signals present within it. This sort of testing is only possible in the electromagnetically "quiet" environment available in an ISTF's anechoic chamber, where adequate simulation and stimulation are also available. For classification reasons, the Navy was not willing to address specific aircraft problems in this arena.

Case 5—Testing requiring signal security. Tests often require a secure environment in which the threat emitter and/or the system under threat can radiate. Only an ISTF with its anechoic chamber provides this capability. We did not discuss specific examples with the Navy, but one such use is the testing of signal war reserve modes.

New Page

FREE-SPACE, FAR-FIELD TESTING

The issues of anechoic chamber size and method of system stimulation (signal injection or use of "antenna hats" versus "free-space, far-field radiation") have been mentioned several times in this paper as technical issues. It is beyond the scope of this paper to explain these issues in detailed technical terms. The discussion below attempts to provide some insight.

Two approaches are theoretically available for stimulating a system under test (SUT) in an anechoic chamber. These are signal injection and "antenna hats"; or free-space radiation. In an ideal test chamber, both would probably be used.

Signal injection and antenna hats involve delivering a signal from a stimulator (e.g., from a threat simulator) to the SUT via cables, where the signal is radiated directly into the receiving antennas of the SUT by means of antenna hats; or is injected directly into the SUT's signal processing circuitry without passing through the antenna.

Free-space radiation means that the radiating stimulator delivers a signal to the SUT by actually transmitting into the chamber, with the SUT's antennas then receiving the signal.

The implication of "far-field" is that the distance between the SUT and the radiating stimulator must be sufficient that the SUT is not subject to phenomena that are so highly localized around the transmitter that an actual system in flight would not be affected by those phenomena.

The theoretical benefits of "free-space, far-field radiation" are that it tests the antennas and any signal processing circuitry imbedded in the antennas, and that it facilitates evaluation of phase measurement performance of the SUT. On the other hand, it creates a more complex overall test simulation environment, and there is significant debate within the test community regarding the physical characteristics an anechoic chamber must possess to permit free-space, far-field testing.

Notwithstanding the complexity of the debate, far-field testing (and its presumed large chamber requirement) had little bearing on our recommendation to proceed with the ECIT at Edwards AFB. Our case can be summarized as follows:

- To satisfy the ISTF requirements, more chamber capacity and a large chamber capability are needed.
- The additional large chamber ISTF capacity can be accomplished by adding a large chamber to ACETEF or by adding facilities (simulation and stimulation labs, and command and control) to the chamber at Edwards. Our cost analysis indicates that ECIT is more cost effective; at the workload levels we believe are likely and with investment, deployment and operating costs we believe are most probable.
- If OSD decides to pursue this option, there is the added potential benefit that the ECIT is more likely to permit evaluation of free-space, far-field techniques, which may or may not work, and may or may not prove to be worthwhile if they do work.

While it would be gratifying to be able to resolve the technical issues identified above, even technical experts in the field have differences of opinion on the subject. We do not believe the issue will be fully resolved soon. On the other hand, we do not believe that the issue is crucial to the ECIT versus ACETEF decision.

The pages that follow contain materials prepared by the Air Force that elaborate on this issue.

POLARIZATION AND PHASE CONSIDERATIONS FOR INSTALLED SYSTEMS TESTING

QUESTION

Why are the polarization and phase characteristics of electromagnetic emissions important for installed avionics systems testing?

ISSUE

This paper discusses the requirements for installed systems test using bi-directional (SUT-to threat and threat-to-SUT) free-space radiation and signal injection techniques.

IMPLICATIONS

The test technique, free space radiation or signal injection, is a driving requirement on test chamber size and its anechoic characteristics. If signal injection is the only stimulation technique is the only stimulation technique required, then the chamber size and its anechoic characteristics are not critical. If free-space radiation is required, then the chamber must not only have good anechoic characteristics, but it must also be sized to provide a "quiet zone" large enough to accommodate the largest article to be tested.

DISCUSSION

1.0 This paper discusses three issues: (1) electromagnetic emission polarization and phase in electronic combat system operation; (2) identification of some avionics/EC systems which use signal polarization and phase to function properly; and (3) importance of testing these type systems through both signal injection and free space radiation.

1.1 Electromagnetic energy, when transmitted through space, has important properties for avionics and their imbedded electronic combat functions. These properties are the frequency, amplitude, polarization, and phase of the energy impinging on the system under test. Because of their importance in evaluating ECM and ECCM functions, the properties addressed specifically in this paper are polarization and phase.

1.2 Polarization and phase measurements are used for determining the direction of arrival (DOA) of energy impinging on the system under test (SUT) and for assessing radar

aperture/scan controller operation under threat exploitation. Most modern and future aircraft weapon systems being developed by the DoD will have electronic combat functions that use transmitted and received signal polarization and phase characteristics. Some ground, air, and sea threat systems exploit signal polarization and phase to defeat the weapon.

1.2.1 ECCM equipment (double jammers, sideline blanking jammers, and stand-off/escort/stand-forward jammers) take advantage of the ECCM functions inside search, track-while-scan (TWS), and track radars. The techniques which these systems employ are called cross-polarization, cross-blinking, and terrain bounce/bounce jam. If these techniques are successful, then the victim sensor's ECCM functions are impaired. This occurs within the victim's radar which is then unable to defend against enemy jamming while targeting and firing weapons.

1.3 One of the objectives of testing electronic combat systems is to effectively replicate the typical combat situations that these systems encounter. The installed systems test facilities, like the Benefield Anechoic Chamber (BAF) should be able to replicate realistic combat situations in a secure and electromagnetically quiet location. However, the challenge to replicate the many electromagnetic emission characteristics for every emitter, on every player, and within a combat scenario is dependent upon electromagnetic characteristics of the anechoic chamber when using free-space propagation or the digital representation when using signal injection.

1.3.1 If the testing technique is signal injection behind the antenna/aperture and scan controller equipment, then the electromagnetic energy wavefront polarization and phase, as well as the antenna characteristics, must be digitally calculated and included in the injected signal. In this situation the antenna/aperture and scan controller are untestable and jamming/countermeasure techniques, which attack the vulnerabilities of this equipment, cannot be evaluated except by digital simulation and analysis of simulation results. Digital simulation will be further complicated by the next generation of weapon system antennas, which will contain active components. Moreover, accurate system performance and effectiveness of the SUT cannot be determined, confidence in system operational performance is reduced, and development risk is increased. The chamber's anechoic properties are not a factor in these types of test; and, generally speaking, the chamber size, if large enough to accommodate the SUT, is not important

1.3.2 On the other hand if the total weapon's effectiveness is to be evaluated, then the system must also be tested by free-space radiation. In this case the SUT antenna/aperture and scan controller must be subjected to the electromagnetic energy source

so that the energy wavefronts are representative of those that occur normally during combat situations. Since the antenna/aperture' and scan controller are included in the testing, their effects on the SUT's performance is an integral consideration during the testing. The whole system is being tested, confidence in system performance is increased, and development risk is reduced.

Testing by signal injection is less demanding on anechoic chamber performance, but has limited utility for SUTs that employ signal polarization and phase characteristics. Free-space radiation provides greater test realism but requires a chamber sufficiently large to create an electromagnetic quiet zone accommodating the SUT (see "Anechoic Chamber Sizing Considerations for Installed Systems Testing"). Depending upon the type of test to be performed, the fidelity and number of threats employed, and the required equipment to be tested, injection and free-space are both desirable test implementation techniques. Each of these implementation techniques has significant purpose and provides a different level of realism. The use of only one technique limits a chamber's usefulness and produces a limited set of test results. This means less system confidence and higher development risk. The optimal implementation is the complementary and synergistic use of both electromagnetic emission techniques to provide realistic environments sufficient to meet tests objectives.

ANECHOIC CHAMBER SIZING CONSIDERATIONS FOR INSTALLED SYSTEMS TESTING

QUESTION

What is the minimum required anechoic chamber size to meet Air Force installed system test (IST) requirements?

ISSUE

Chamber size is a critical factor in the ability to accommodate testing with bi-directional free-space radiation of electromagnetic signals emanating from both the system under test (SUT) and the threats being tested against. Minimum quiet zone size and energy source minimum distances from the SUT are critical to accommodate Air Force test requirements.

IMPLICATIONS

If the anechoic chamber is not sufficiently large, then all Air Force test requirements may not be accommodated.

DISCUSSION

1.0 Summary of Analysis: Attached is part of the analysis, "Technical Plan for the Design/Build Phase of the Air Force Anechoic Facility", accomplished by the Air Force, under contract to Rockwell International, to design and build the Benefield Anechoic Chamber at Edwards AFB. Below is a quick summary of the considerations that were made by the Air Force to arrive at a design that was the minimum necessary to accommodate the Air Force requirement, not just for the B-1B, but also for other large Air Force weapon systems, such as the B-52, C-17, EC-130, B-2.

- Dimensions of the B-1B: Wing Span 137 ft, Length 147 ft, Height 34 ft
- Minimum clearance between the chamber RF absorber surface and the aircraft under test is 15 ft. (This provides a free-space loss of from 52 dB at 1 GHz to 77 dB at 18 GHz when combined with the RF absorber loss, a minimum chamber isolation in the test zone of over 100 dB will be attained.)

- In order to properly test the aft section of the B-1B, a minimum separation of 75 ft between the chamber RF absorber surface and the tail radome is required. This means that the aircraft will not be centered in a minimum sized chamber.
- B-52 and C-17 Design Considerations

When all of the above factors are considered, it can be shown that the minimum chamber requirements (including RAM dimensions) for the B-1B are 241 ft long X 171 ft wide X 68 ft high. When the B-52 and C-17 requirements are considered in conjunction with the B-1B the minimum acceptable dimensions become 260 ft long X 240 ft wide X 70 ft high.

2.0 Power Dissipation Considerations: The attached Technical Plan indicates that the high-powered B-1B offensive radar system is capable of operating in a chamber (with dimensions as given above) with a low power absorber material capable of dissipating only 2 watts per square inch. Since absorber material either has high power dissipation capacity or high absorption but not both, a similar evaluation must be performed on any new design to insure that the chamber is large enough to use the low power high absorption material, otherwise the more expensive high power material must be used.

3.0 Additional volume provided by a chamber that will accommodate large as well as small SUTs will result in more valid test results by providing longer propagation paths for multipath error signals and as a consequence lower corruption of actual test signals and installed avionics systems response.

CONCLUSIONS

Air Force test requirements for an installed system test facility includes the requirements to test both by signal injection and by bi-directional free-space radiation (see "Polarization and Phase Considerations for Installed Systems Testing"). This requirement, as well as other requirements dictated by power and signal handling capacities, dictate the need for an anechoic chamber of sufficient size to accommodate all Air Force weapon systems, small, large, and multiple aircraft.

Based on Air Force analysis, the smallest chamber that will support the Air Force requirement is an anechoic chamber with the inside dimensions at least 260 ft long X 240 ft wide X 70 ft high.

POTENTIAL FOR USE OF ANECHOIC CHAMBER FACILITY AT GRUMMAN AIRCRAFT, CALVERTON, NY

The Navy-owned chamber at Calverton is roughly the size of the ACETEF chamber, with very limited supporting laboratories. Providing it with the capability to support testing similar to the existing ACETEF capability would require an investment comparable to that which IDA estimates for the ECIT—and would still provide no capability for testing of large aircraft.

	ACETEF	Grumman
Size	60' × 100' × 40'(h)	87' × 87' × 42(h)
Door	40' × 20'(h)	80' × 40'(h)
Crane	30 ton	30 ton
Frequency Range	0.5 to 94 GHz	0.06 to 18 GHz
IOC	1983	1969
Uses	EMC, EW, EC, Aircraft Systems Integration	EMC, EMI, Radiation Hazard
Category	II+ Cat I planned	III

Limitations of the Calverton chamber:

- The chamber at Grumman cannot handle the "large chamber" requirements.
- It possesses very limited stimulation and no simulation capability. It can generate *dozens* of relatively non-complex signals compared to *hundreds* of relatively high-fidelity threats available in ACETEF.
- There is no man-in-the-loop capability.
- It cannot provide many-on-many test scenarios.
- There is no capability to "fly" the test article in a complex mission.

Utility of the Calverton facility:

- The chamber has been used to support tests of more than 90 aircraft.
- Its low-frequency performance (60 MHz to 500 MHz) is superior to ACETEF or BAF.
- Its absorbent cone material (horse hair) permits higher radiated power in the chamber.
- It is big enough for some aircraft (E-2C) that will not fit into ACETEF.

- Where test users do not require complex mission scenarios and threat environments, the facility is available and may provide adequate test capability.

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REFERENCES

ABBREVIATIONS

AATF	Aircraft Anechoic Test Facility
ACETEF	Air Combat Environment Test and Evaluation Facility
AF	Air Force
AFB	Air Force Base
AFECO	Air Force Electronic Combat Office
AFFTC	Air Force Flight Test Center
ASEF	Aircrew Systems Evaluation Facility
ASL	Aircrew Systems Laboratory
ATLAS	Antenna Test Laboratory Automated System
BAF	Benefield Anechoic Facility
CNIL	communications, navigation and identification
CTEIP	Central Test and Evaluation Investment Program
CTF	Combined Test Force
DoD	Department of Defense
DT&E	development test and evaluation
E^3	electromagnetic environmental effects
E^3TL	Electromagnetic Environmental Effects Test Laboratory
EC	electronic combat
ECIT	Electronic Combat Integrated Test (AFFTC)
EMEGS	Electromagnetic Environment Generating System
EO	electro-optical
EW	electronic warfare
EWISTL	Electronic Warfare Integrated Systems Test Laboratory
FLIR	forward-looking infrared
FY	fiscal year
FYDP	Future Years Defense Program
GTRI	Georgia Tech Research Institute
I&M	Improvement and Modernization
IDA	Institute for Defense Analyses
IFAST	Integration Facility for Avionics Systems Test
IFF	identification friend or foe

INATS	Integrated Avionics Test Station
IR	infrared
IRST	infrared search and track
ISTF	Installed System Test Facility
LAC	large anechoic chamber
MFS	manned flight simulator
MILCON	Military Construction
MRTFB	Major Range and Test Facility Base
MTP	Manage to Program
NAS	Naval Air Station
NATC	Naval Air Test Center
NAWC	Naval Air Warfare Center
NAWC-AD	Naval Air Warfare Center-Aircraft Division
NIFFTE	Navy Identification Friend or Foe Test and Evaluation
OCC	Operations and Control Center
OSD	Office of the Secretary of Defense
OSL	Offensive Sensors Laboratory
OT&E	operational test and evaluation
P^3I	Pre-Planned Product Improvement
PE	program element
PMA	program management activity
POM	Program Objectives Memorandum
PRIMES	Preflight Integration of Munitions and Electronics Systems
R&M	reliability and maintainability
RCS	radar cross-section
RDT&E	research, development, test and evaluation
RF	radio frequency
RTS	Radar Test System
RUMS	Range Utilization Measurement System
SAC	small anechoic chamber
SH	shielded hangar
SIL	systems integration laboratory
SPO	Systems Program Office
SUT	system under test
SWEG	Simulated Warfare Environment Generator
TASTEF	Tactical Avionics Software Test and Evaluation Facility

TEMS	Test and Evaluation Mission Simulator
TIS	test information sheet